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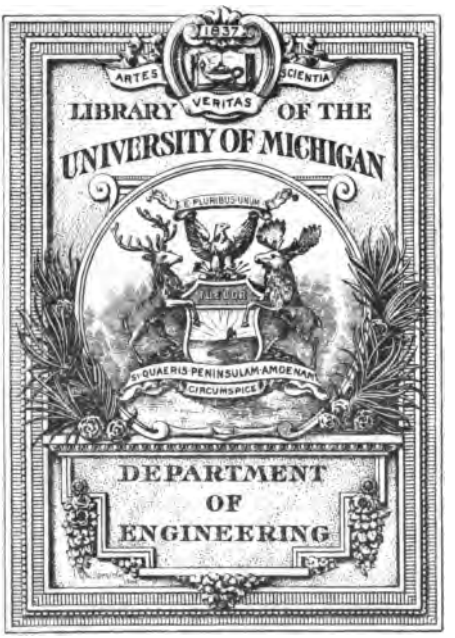

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SWITCHBOARDS

FOR

Power, Light and Railway Service—

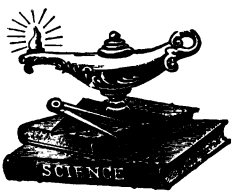
Direct and Alternating Currents—

High and Low Tension

BY

WILLIAM BAXTER, Jr.

Author of "Commutator Construction," etc.



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1910

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Switchboards

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In a very small, isolated plant, where a single generator is used, the current can be conveyed to the apparatus in which it is utilized in a comparatively crude manner; all, in fact, that is required being suitable conducting wires to complete electric circuit. If there are several generators, feeding into a more or less complicated network of distributing wires, the circuit connections will become complicated unless a systematic way of arranging them is resorted to. There will be considerable complication even if only one generator is used, providing the distributing system is complicated. To simplify the arrangement of the wiring, the best course of procedure is to run the wires leading from the generator, or generators, to a central point, and then from there branch out to the various distributing circuits. This central point to which the generator wires are run, and from which the circuit wires start, is called a switchboard. The general arrangement of a switchboard depends very largely upon the service it is to perform, and also upon the type of current it is to handle. For continuous currents we have the constant potential and the constant current systems, and each one requires a switchboard arranged in a decidedly different manner. For the alternating current systems we have the single phase and the polyphase, both being of the constant potential type. Constant current alternating currents are very seldom

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used, except for "arc" lighting. As the continuous current systems are the most simple we will start the discussion with these, taking up first the constant potential switchboard.

The switchboard, in the strictest sense of the word, is not an indispensable adjunct of an electrical installation, and in fact was unknown for several years after the introduction of electric lighting. It first came into use, in a very crude form, as a matter of convenience; it was gradually elaborated, and at the present time is regarded as a part of the system only second in importance to the generator itself. It belongs to that vast class of apparatus that first come into use as a luxury and finally come to be regarded as a necessity. At the present time we would consider it impossible to operate a boiler without a steam gauge, but they were so used in days gone by, and if we had no gauge we could get along without it. These remarks are equally applicable to the electrical switchboard.

In the early days of "arc" lighting the wires from the binding posts of the dynamo were run directly out to the lamp circuit, in most cases not even a switch being used. Whenever it became necessary to discontinue the lights, the dynamo was stopped. Before long it became evident that a switch introduced into the circuit would be a convenience, as then it would be possible to put out the lights without stopping the dynamo, and this certainly would be advantageous in cases where it was desired to suspend the lights for only a few minutes. In this way the switch for opening the line came into use. Very early in the history of "arc" lighting it was discovered that unless the current remained practically uniform, the

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lamps would not burn steadily; hence it became desirable to have an instrument whereby the current strength could be indicated, and this brought into use the ammeter. With incandescent lighting it was soon found that uniformity of pressure was the point of vital importance, and thus the voltmeter was introduced in such installations. In "arc" lighting the current remains of constant strength, therefore there is no danger of burning out the generator by overloading. In the incandescent lighting system the case is different; each lamp adds its quota to the current strength required, and if the number of lamps is sufficiently increased, the current will become strong enough to burn out the generator, providing there is enough power behind it to keep it running. To prevent burning out generators of the incandescent type, by overloading, safety devices were gotten up; these acting by opening the circuit and thus stopping the flow of current whenever the danger limit is reached. There are two types of safety devices used to avoid the destructive effects of overloads; one is the "safety fuse," which is simply a piece of wire of such size that it will be melted by a current of sufficient strength to injure the generator, and the other is the "circuit breaker," which is actuated by a magnet, the strength of which is exerted in opposition to a spring or some other counteracting force. The strength of the magnet increases with the current, and when the predetermined point is reached, the device acts, as at that point the force of the magnet is sufficient to overcome the reactive force.

Generators used for incandescent lighting are designed to develop the required pressure at a certain velocity of rotation, but it frequently happens that for one reason

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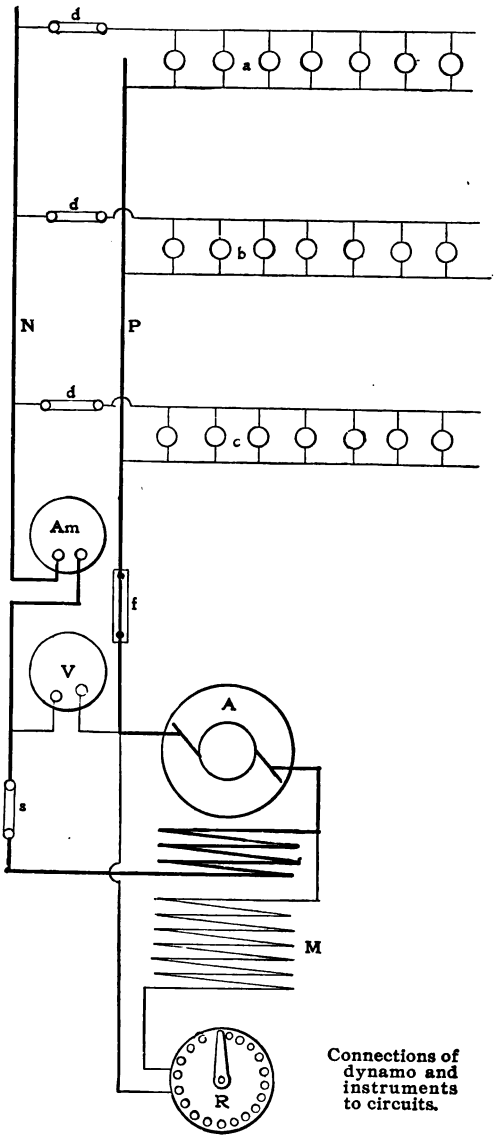

Connections of dynamo and instruments to circuits.

Figure 1. *The Derry Collard Co.*

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or another it is not practicable to obtain just this speed. In order that the generator may be able to develop the desired voltage, even if the velocity is somewhat varied, a device is provided by means of which the pressure may be increased or decreased without changing the velocity. This device is simply a resistance, or rheostat, and is called a field regulator. If the voltage of the generator is too high, a sufficient portion of the regulator resistance is thrown into the circuit of the generator field coils to bring it down to the required point, and if the voltage is too low the regulator resistance is cut out.

From the foregoing it can be seen that to successfully operate a single constant potential generator all we require is a field regulator, a circuit breaker, an ammeter, a voltmeter and a switch to open the circuit. To this we should also add switches for opening independently the several branch circuits. From Fig. 1 an idea of the devices and the manner in which they are connected can be obtained.

Before proceeding to explain this diagram it will be well to show the connections of the generator independently of the distributing circuits, showing the connections for compound as well as shunt wound machines. In Fig. 2 the generator connections are shown for a simple shunt two-pole generator. At *V* a voltmeter is placed which indicates the *e m f* developed, and, as will be noticed, it is connected directly across the main lines by wires *g g*. At *Am*, an ammeter is connected in series in the line *N*, and it measures the strength of the current in amperes. At *R*, the field regulating rheostat is located, being placed as shown by wires *f f* in series in the shunt field coil circuit.

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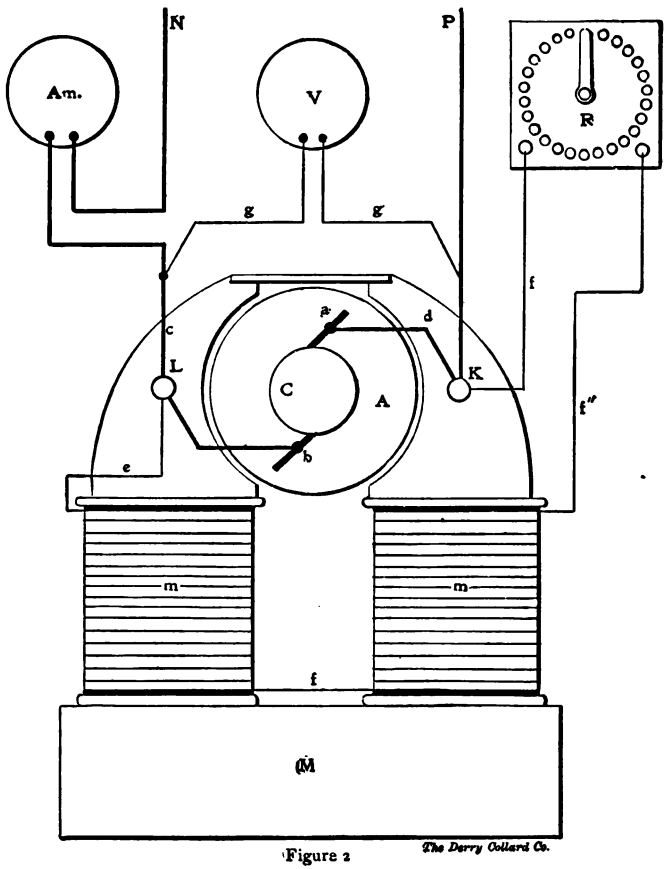

Figure 2

Connections for a two-pole shunt generator, including instruments and rheostat.

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Shunt and compound winding.

If we drop the outline of the motor, and represent simply the field coils and the armature, then this diagram can be simplified to the form shown in Fig. 3.

In Fig. 4 a diagram of the same type as Fig. 3 is given which shows the connections for a compound wound generator. As will be noticed, the connections with the in-

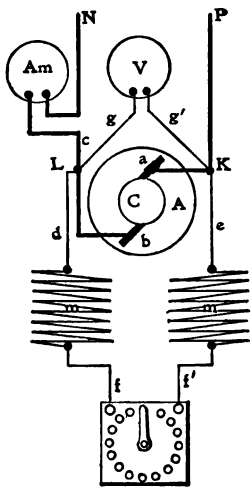

Figure 3

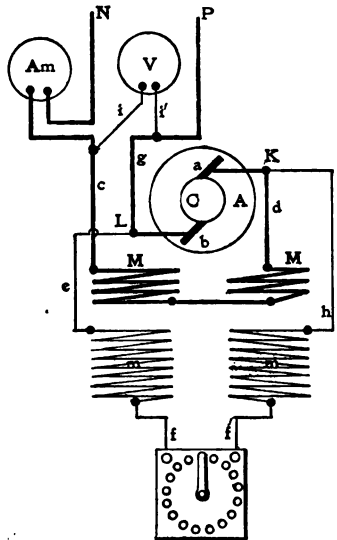

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Figure 4

Outline representation of shunt and compound wound generators.

struments and with the field rheostat are the same as for the shunt machine. In this diagram the series coils are connected in successive order, and the armature is at one end, but when the generator is intended to be used singly, the armature can be connected between the series field coils, as in Fig. 5, or as in Fig. 6. In the first

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one of these two diagrams, the shunt field coils are connected by the wires *e* and *h* directly with the leads from the commutator brushes, so that the coils *m m* shunt the armature only. This connection is called the short shunt, and is the one most generally used, and, in fact, the only

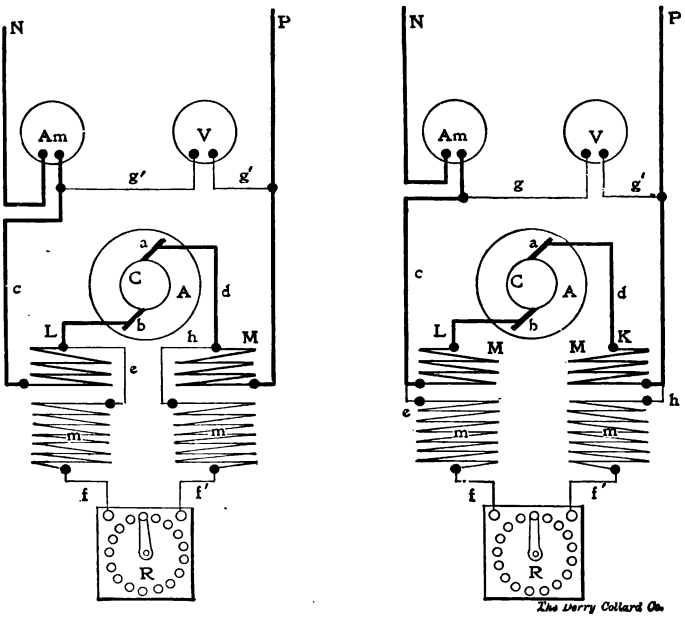

Figure 5 Figure 6

Other methods of connecting generators.

proper one if close regulation of the voltage is desired. In Feg. 6 the shunt coils lead off from the ends of the series coils, thus shunting these coils as well as the armature. This is called the long shunt.

Sometimes the shunt coils as well as the series are connected, apparently at one side of the armature as

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illustrated in Fig. 7, but on close examination it will be found that the shunt coils straddle the armature, so that the connection is precisely the same as in Fig. 4. In connecting the shunt coils care should be taken that they are not arranged as in Fig. 8, for with this connection

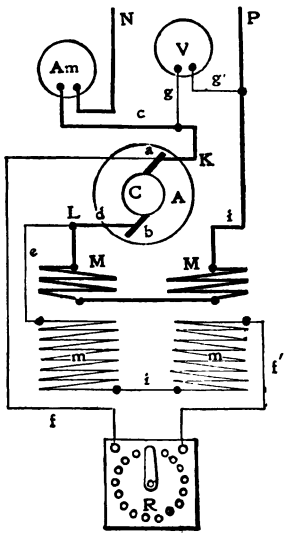

Figure 7
The long shunt.

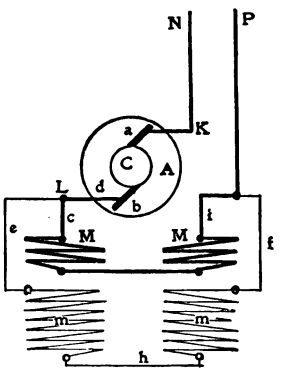

Figure 8
The Derry Villard Co.

This shows how not to do it. Shunts field coils but not armature.

they would shunt the series field coils *m m* and not the armature.

Multipolar machines of the compound type are connected as in Fig. 9, and in some cases, where the capacity is great, the series coils are placed in parallel, as in Fig. 10. In both these diagrams it will be seen that the voltmeter and the ammeter are connected in the

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same way as in the diagrams of two-pole generators, the wires *g g* connecting with the two mains *P* and *N*, and the ammeter being in series in one of the mains. It may

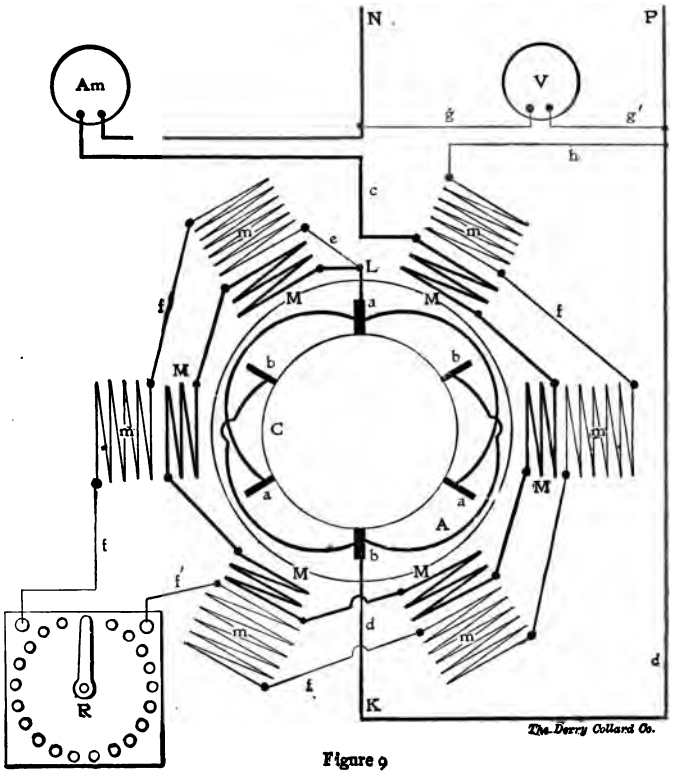

Figure 9
Compound connections for multi-polar generator.

be well to mention here that it is immaterial in which one of the lines the ammeter is placed, as the current is the same in both.

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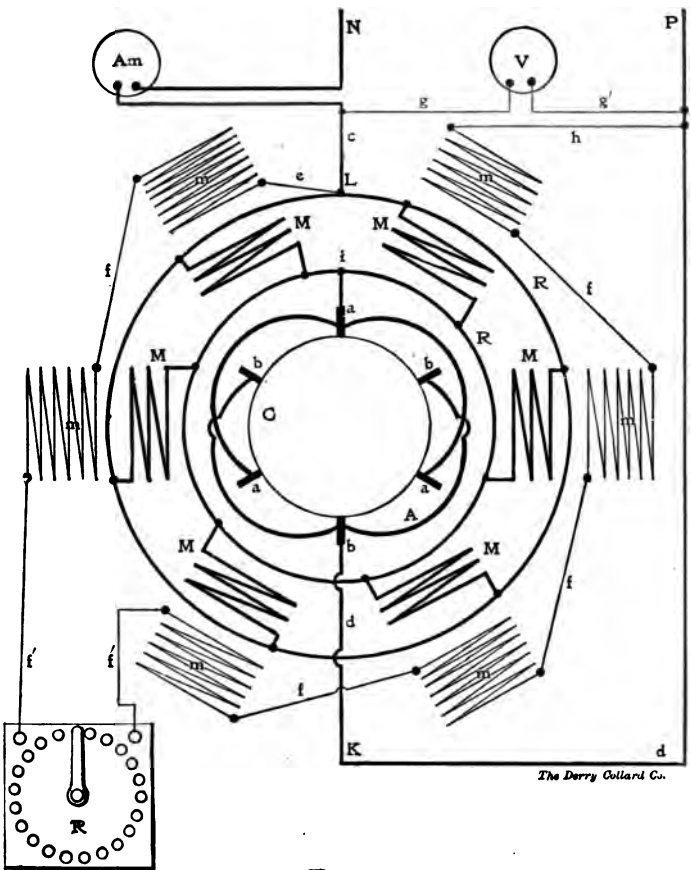

Figure 10

Series coil in parallel on large multi-polar generator.

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Connections for distributing circuits.

With the foregoing explanation of the connections of the generator proper with the indicating instruments and the field regulator, we can return to Fig. 1 and consider the connections with the distributing circuits. In this diagram, the circle *A* represents the generator armature, and *M* is the shunt field coil, or more properly, the representation of all the field shunt coils, whatever their number may be. In the same way the coil above *M* represents the series coils. The field regulator is at *R*, the voltmeter at *V* and the ammeter at *Am*. The main switch is shown at *S*, the circuit breaker at *f*, and the branch circuit switches at *d d d*. It will be evident at once that it is immaterial in what part of the engine or generator room these various devices are located so long as they are where they can be seen and readily reached when desired. As to the switches *d d d*, it is not necessary that they should even be in the same room as the generator, for they can be placed at the points where the several circuits branch off. It can be readily realized, however, that if they are located in some systematic order at some convenient point they will not only present a more methodical appearance, but will actually become a greater convenience. A switchboard is nothing more nor less than a board upon which these several devices are arranged in systematic order. For the case shown in Fig. 1 the switchboard would assume the appearance shown in Fig. 11. Here we see that the field regulator is located at the bottom of the board between the main switch *S* and the circuit breaker *C*. Before the days of switchboards the field regulator was generally located on the floor by the side of the generator, and the voltmeter, am-

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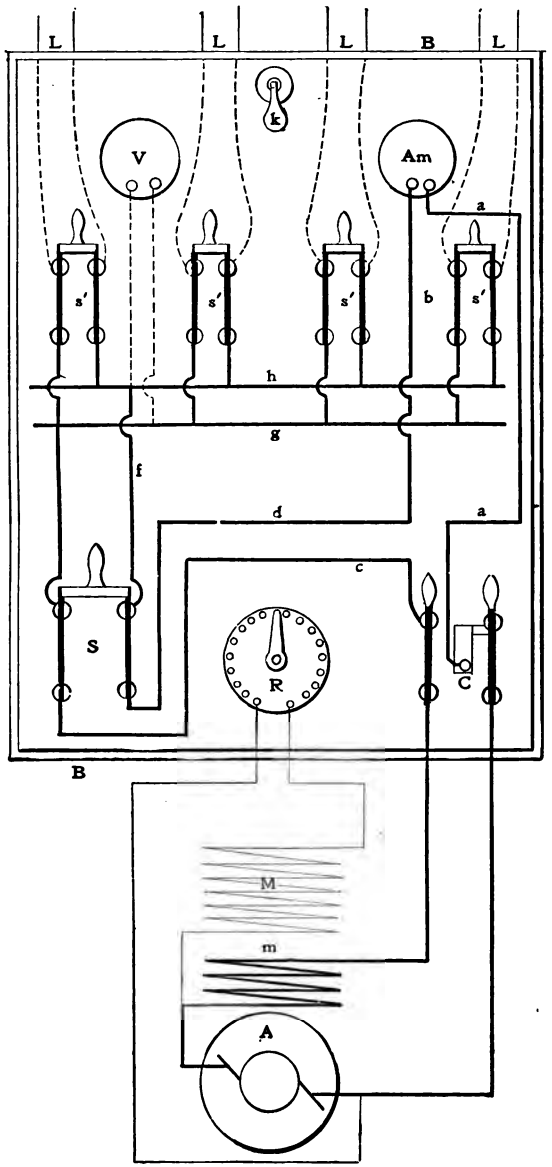

Figure 11 *The Derry Collard Co.*

A simple switchboard.

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meter and other devices were strewn along the wall wherever there was an available space.

In the regularly organized board of Fig. 11 the voltmeter and ammeter are located at the top. By tracing the lines that indicate the circuit wires it will be seen that the line runs from the right side brush of the generator to the circuit breaker, and from the central contact of this to the ammeter, by wire *a*, and thence, by wire *b*, to wire *d* to the bottom of the main switch *S*, from which it passes by *f* to wire *h*. The wires *h* and *g* are called bus bars, as they form a common terminus from which the several circuits controlled by the small switches *s' s'* are derived. If the branch circuits *L L L* are very numerous the board *B* can be made wider, if there is room in the place where it is located to increase its dimensions in that direction. If such is not the case, its height can be increased, and the *s'* switches can be placed in two or three rows one above the other. An incandescent lamp placed at *k* serves to illuminate the board so that the attendant may be able to see the position of the switches and take readings of the instruments at all times.

In Fig. 1 it will be noticed that the ammeter is placed so that all the current of the generator passes through it, but the voltmeter is in a circuit of its own, between the wires *N* and *P*. The ammeter is an instrument of very low resistance, and as it measures the strength of the current, all the current must pass through it; but the voltmeter measures the pressure; hence, it must be acted upon by the total pressure, and to be so acted upon, it must bridge the circuit from one side to the other, that is, from wire *N* to wire *P*. The amount of current that

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passes through the voltmeter is very small, owing to the fact that it is wound with fine wire and its resistance is very high. In Fig. 11 the voltmeter wires connect with the busses *g* and *h,* but these, as will be found by tracing the wires, are the two sides of the circuit, just as the wires *N* and *P* in Fig. 1 are.

The switchboard should be placed in a vertical position, near the wall, but not so near as to interfere with the thorough inspection of the connections on the back of it. The distance between the wall and the back of the board should be from three to four feet. All the wires are placed on the back of the board, and the switches, circuit breaker and instruments are on the front. The field regulator is also placed on the back, and only the handle projects through to the front.

If it is desired to stop the current, the switch *S* is opened, and unless the current is not to be used for several hours, it is unnecessary to stop the generator. If we desire to stop the flow of current in any one of the distributing circuits all we have to do is to open the *s'* switch that controls that circuit. By having the field regulator located on the switchboard, the adjustment of the generator to the proper voltage is greatly facilitated, for the attendant can turn the regulator handle while watching the voltmeter, and thus see just when the proper adjustment is effected.

In some cases it is desirable to arrange the external circuits into two or more independent distributing systems, and to have the connection with the generator so arranged that any one system may be operated alone or all at the same time. If the external circuits are divided into two independent systems, the arrangement of the switch-

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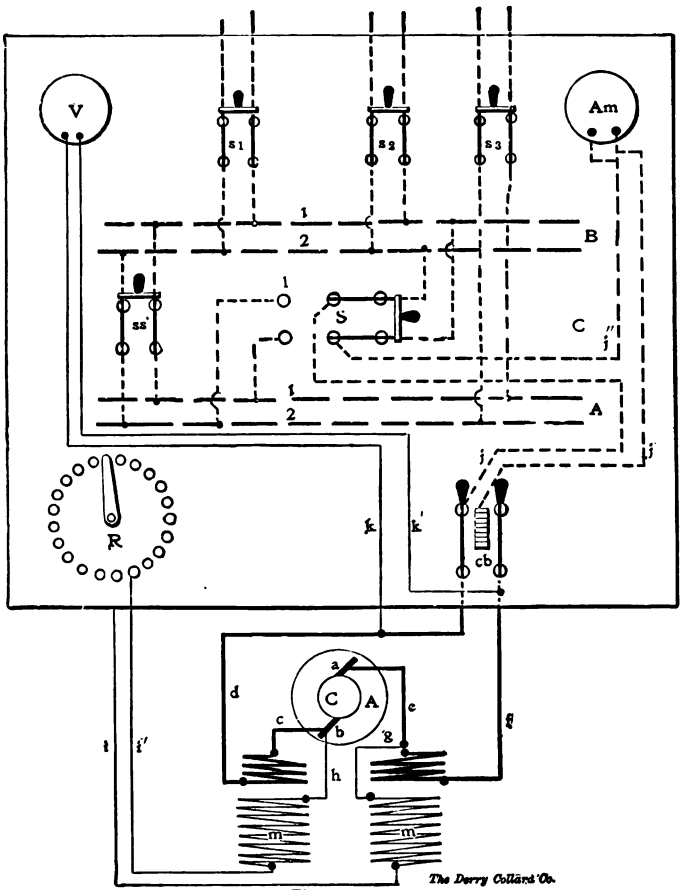

Figure 12

A switchboard for three circuits.

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board is less complicated than when there are three divisions; and three divisions cause less complication than four, and so on, for any greater number. In Fig. 12 is illustrated the manner of making the connections when the external circuits are divided into two systems, and from this diagram, the method employed with a greater number of systems can be readily understood.

From the circuit breaker *c b* the current passes to the top center contact of the main switch *S* by wire *j*, and by wire *j'* to the ammeter *A M* and thence by wire *j''* to the lower center contact of the same switch. The main switch is of the type called double-throw, that is, it can be thrown to the right or left. When thrown to the right the current passes to the right side contacts, and from here to the *B* busses at the top of the switchboard. If the switch is thrown to the left it will connect the center contacts with those on the left side, marked *i*, and then the current will pass to the lower busses, marked *A*. The small switches, *s1 s2* are shown connected with the upper busses *B*, and the switch *s3* is connected with busses *A*. The switch, *s s*, is provided for the purpose of connecting the two sets of busses, and when it is closed the generator will feed into the entire system, regardless of what direction the main switch *S* may be in; but when *s s* is open the current will pass to the busses with which *S* is connected.

From the foregoing it will be seen that by this arrangement we can connect the generator with the upper or the lower busses independently, or we can connect it with both by closing the *s s* switch.

Buildings in large cities that are provided with a lighting plant are, as a rule, arranged so that current may be

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drawn from the street mains should the machinery get out of order or should it be desired to shut down for any cause. The street mains are always arranged upon the

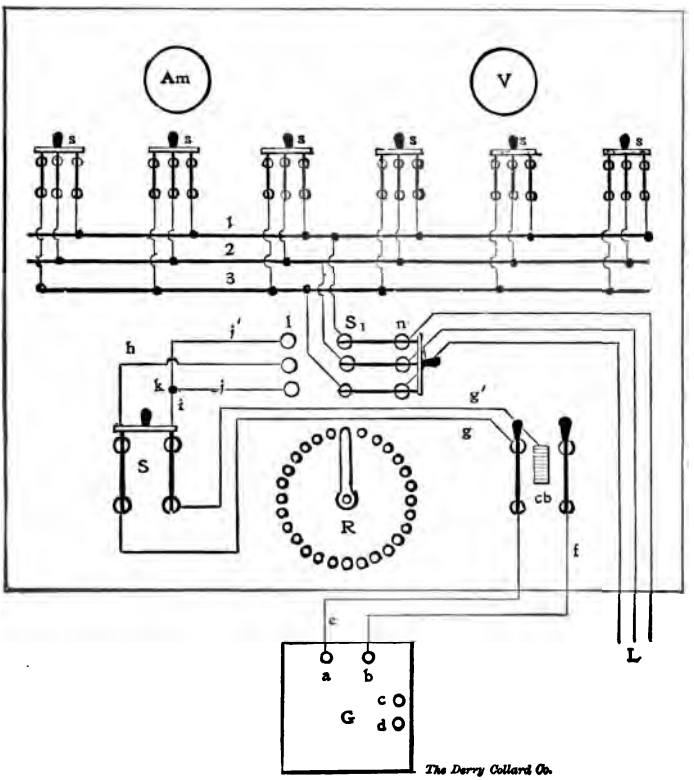

Figure 13

Current passes through circuit breaker first.

three-wire system, while, as a rule, the plant in the building operates upon the two-wire system. The latter system is preferred for private installations, owing to the

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fact that the lights can be turned on or off without any danger of unbalancing the system, while with the three-wire system such unbalancing is possible, and in small installations very probable. When a building is wired so as to be supplied from the street mains upon the three-wire system, and from the house plant upon the two-wire system, the arrangement of the switchboard, for a simple case involving the use of but one generator, is about as shown in Fig. 13. In this diagram, *G* represents the generator located in the building, and *L* represents the three wires leading in from the street mains. The generator connects first, with the circuit breaker, *cb*, and then with the two-pole switch, *S*. From the right upper contact of this switch a wire, *i*, runs out and branches into the two parts, *j j'*, which are connected with the top and bottom contacts on the left side of the double-throw switch S_1. The wires *L* from the street mains are connected with the contacts on the right of this S_1 switch. When the generator is in use, the current from binding post *b* passes to busses 1 and 3, and the current from post *a* passes to bus 2. It will thus be seen that if bus 2 is negative, busses 1 and 3 will be positive. When the street wires are to supply the current, the switch S_1 is thrown in the direction shown in the diagram—that is, to the right—and then each one of the three wires connects with one of the busses.

When the street service is used, the current flowing through the central wire, or bus 2, which is the neutral wire, is much smaller than that through the other wires, and will be nearly zero if the system is properly balanced. When the current is supplied by the generator *G*, the center wire will carry as much current as the

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other two combined; hence the center wire must be made of double the cross section. Thus it will be seen

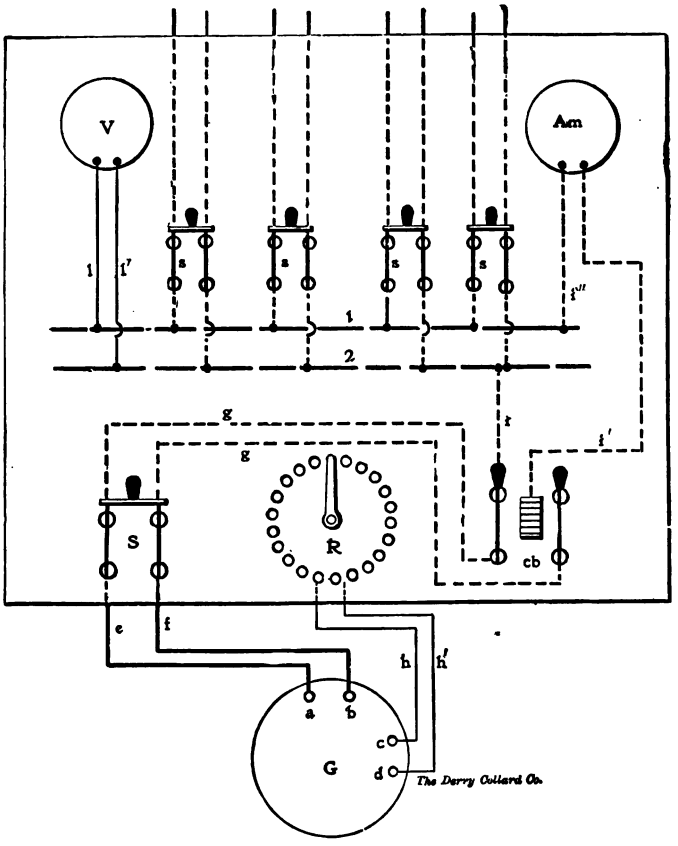

Figure 14
Current passes through main switch then to circuit breaker.

that, while in a regular three-wire system the neutral wire is smaller than either of the other two, in some cases

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being only one-third the size, a building wired for two-wire house supply, and three-wire street supply will have the neutral made of a cross section equal to the other two wires combined.

In Fig. 13 the generator is represented by a simple square, with circles *a b c d* to represent the terminals of the armature and the field coils respectively. This construction is used for the purpose of simplifying the drawing, and for the same reason, the connection between *c d a* and the regulator *R* are omitted. In Fig. 11 the wires from the generator are shown connected with the circuit breaker, but they can also be arranged as in Fig. 14 so as to have the current pass first through the main switch and then through the circuit breaker. With some types of circuit breakers, this arrangement is necessary.

▼ ▼ ▼

Operating Generators in Parallel.

When it is desired to operate two or more generators in parallel, that is, so as to feed into the same system of external wires, the simplicity of Fig. 11 cannot be preserved, for then it becomes necessary to provide means that will prevent one of the generators from taking more than its share of the load. If the machines are of the simple shunt-wound type, nothing can be done to equalize the work between them, except to adjust the field regulators so that all the generators develop the same voltage; and if they are all of the same size and design, so

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that the variation in pressure will be the same, practically, in all as the current strength changes, no one machine will be likely to take a portion of the load differing from its proper proportion by more than a few per cent.

The way in which two shunt-wound generators are connected is shown in Fig. 15, only the generators and

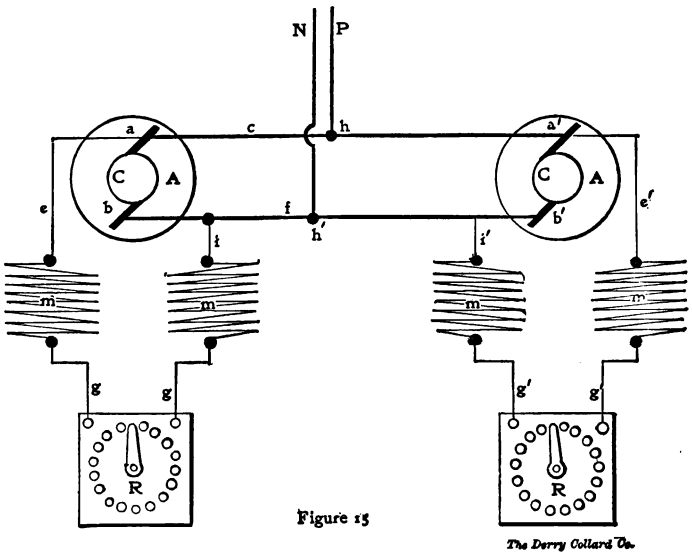

Figure 15

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Two shunt wound generators in parallel.

field regulators being represented, so as to avoid complication. Three, four or any other number of shunt machines would be connected in the same manner; that is, with all the *a* brushes connected with one bus bar, and all the *b* brushes with the other bus. Shunt-wound generators, however, are seldom used owing to the fact that they cannot maintain as uniform a voltage as the com-

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To equalize strength of current.

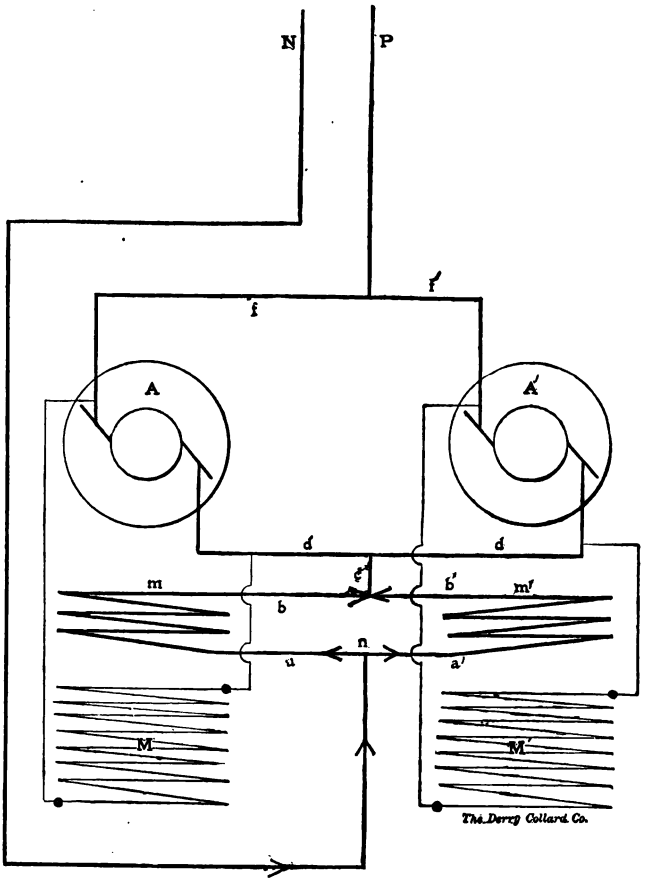

Figure 16

Connected to equalize strength of current in series of coils of both machines.

pound type. When two or more generators of this latter type are connected in parallel it is necessary to so connect the series coils that the strength of current passing through them will be the same in all the machines. This

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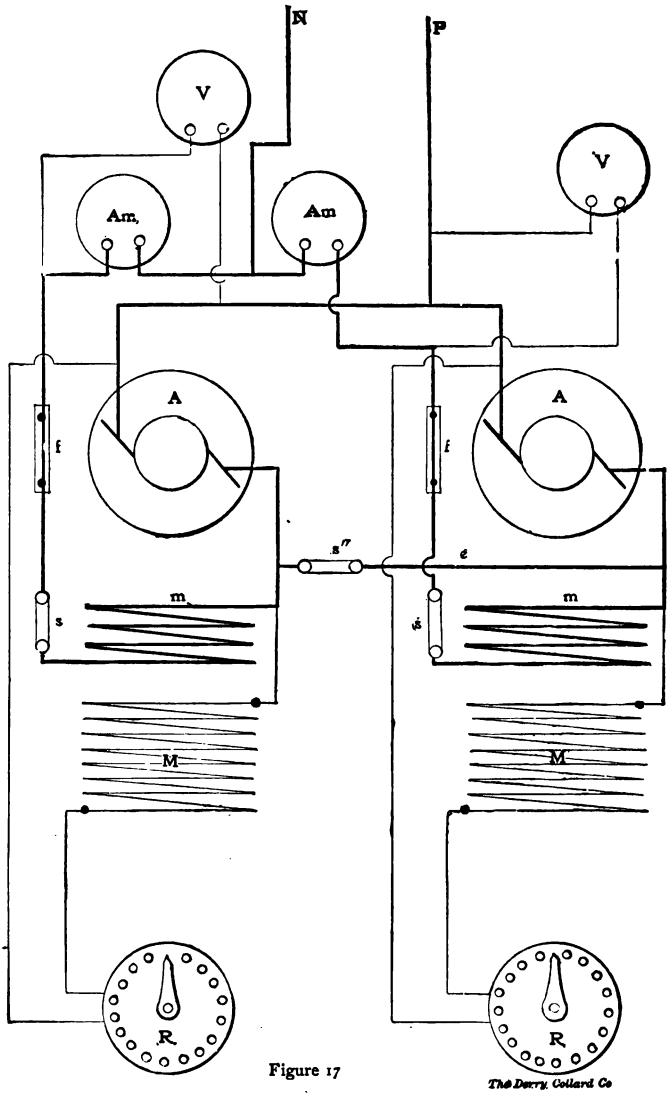

Figure 17

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Two generators in parallel with instruments connected in place.

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result is attained by the type of connection shown in Fig. 16. By examining this diagram it will be seen that the lower ends of the two series coils are connected with each other, and that this is also the case with the upper ends. As *m* and *m'* are of the same resistance, or nearly so, in generators of the same size, the current coming through wire *N* will divide upon reaching *n*, one half passing to *m*, by wire *a*, and the other half to *m'*, by wire *a'*. Through wires *b* and *b'* the current will reach the short wire *c*, and from here it may, and it may not, pass in equal amounts by the wires *d* and *d'* to the two armatures. If the wires *b b'*, *d d'* and *c* were not provided, and the current from armature *A* passed directly to coil *m*, and that from armature *A'* to coil *m'*, then the current flowing in these coils would be of the same strength as that in the respective armatures. Under these conditions any tendency for the generators to run unequally would be aggravated, for the armature developing the strongest current would be acted upon by the strongest field coil, and the effect of this would be to still further increase its current in consequence of the increase in voltage due to the increased strength of the field. When the wires *d d'*, *b b'* and *c* are added, which are called the equalizing connection, the current generated by the two machines is equally divided between the two series coils *m* and *m'*, and the result is that the difference in the strength of the currents generated in the two armatures cannot be very great.

For the operation of two generators in parallel the instruments and apparatus required and the connection of the circuits must be as indicated in Fig. 17. This diagram shows the various parts without any reference to systematic arrangement. We have, as in the case of the

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single generator, a field regulator for each machine, and also an ammeter and a voltmeter; these being shown at *Am* and at *V*. At *f* and *f'* are shown the circuit breakers, and at *s* a switch for opening the circuit of the left-side generator, while at *s'* is a similar switch for the right-side generator. In this diagram the wire *e* is the equalizing wire and takes the place of the wires *d d'*, *b b'* and *c*, in Fig. 16.

If we were to open switch *s*, the left-side generator would not be entirely disconnected from the other one, for through wire *e* the current of armature *A'* could pass to and through armature *A* and to line wire *P*; thus short-circuiting armature *A'* through armature *A*. To be able to entirely disconnect the two generators it is necessary, therefore, to provide the additional switch *s''*. When the generators are running, it is not safe to open the switch *s''* in the equalizing wire before the *s* switch is opened, and when it is desired to cut the second machines into the circuit, it is not safe to close the *s''* switch first. To avoid accidents by the improper manipulation of these switches, it is necessary to provide switches that combine *s* and *s''* in one, so that by the movement of a single handle both circuits are opened. Such switches are called two-pole switches. Even with this arrangement we would not be able to entirely disconnect either one of the generators from the circuit; for, as will be noticed, if the switches *s* and *s''* are opened, the armature *A* will still be connected with the line wire *P*; hence, if *A* were grounded, both generators would become useless. For a complete separation of the two machines we must have another switch in the wire running from line wire *P* to armature *A*.

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Arrangement of Instruments and Switches.

In what follows, it is proposed to explain the general arrangement of the switches, instruments and other apparatus, and also to show how they are connected with each other and with the generators and the external circuits. No general rule can be given for the location of the various devices or for the circuit connections, owing to the fact that in each case the conditions are different; therefore, each particular board must be treated as an independent problem, and the disposition of the parts must be such as to best meet the particular requirements. Since no general rules can be laid down, the only course of procedure left is to present practical examples of boards that have actually been made, and by explaining the conditions they have to fulfill, throw light upon the subject that will serve to show the proper course to pursue to obtain the best results. In some cases the conditions to be fulfilled are few and easily met, while in others the conditions are numerous and of necessity involve a considerable amount of complication. If we have two generators, and desire to connect them to feed into a single system of circuits, the arrangement of the switchboard becomes a decidedly simple matter. On the other hand, if we have two generators, and desire to so arrange them that they may feed into several independent circuits, and be so disposed that either one of the generators may feed any one of the

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distributing circuits or all of them, and further, that one machine may feed some of the circuits while the other feeds the balance, then we will have a complicated arrangement, and may have to exercise our ingenuity to the fullest extent to avoid the use of unnecessary switches, etc., and to avoid too great a complication in the circuit connections.

Fig. 18 shows an arrangement of switchboard for two generators, that may be classified as belonging to the simple type. In this case the generators are required to feed into a single system of distributing circuits, and the only other condition to be fulfilled is that the board must be so arranged that if for any cause the generators fail to operate, current from the street mains may be turned on at once. From the explanation which follows, the manner in which these results are attained will be understood.

As was explained in the last section, it is necessary when two or more generators are operated in parallel, to connect the entering ends, as well as the leaving ends, of all the series coils, so that the current may divide equally between all the generators. In Fig. 18 the equalizing connection runs to the center contact of the main switches S and S'. The connections from the ends of the series coils run to the right-hand side contacts of these switches, and the connections from the left-hand armature terminals connect with the left-hand contacts. If switch S is opened, the left-hand generator will be cut out of the circuit, and if switch S' is opened, the right-hand generator will be cut out. When either one of these switches is closed, its respective generator is connected with the circuit, the center contact, which is the

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A simple switchboard.

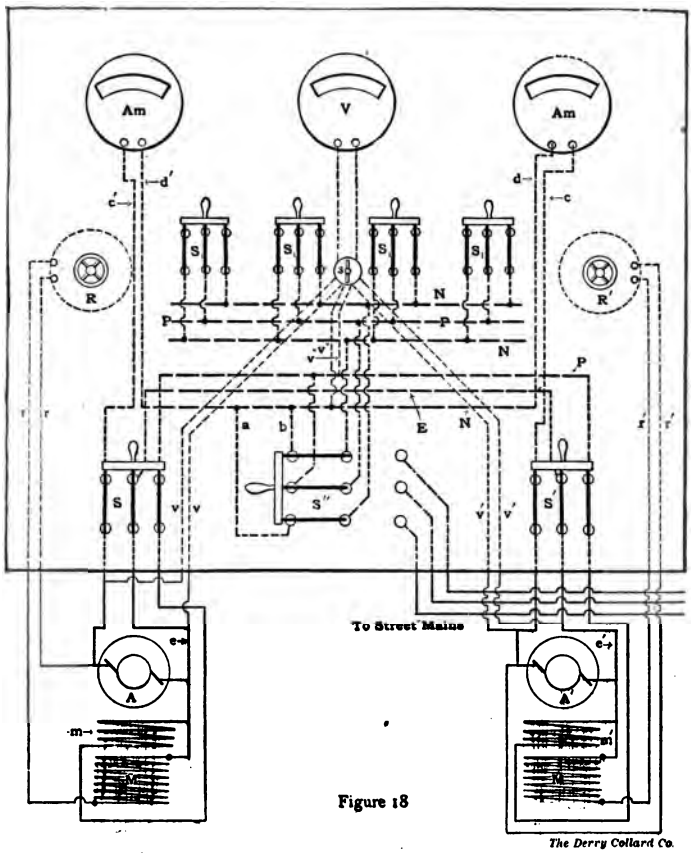

Figure 18

A simple switchboard arranged for two generators.

equalizing connection, connecting with the center bus *E*, which is called the equalizing bus. If the two switches are closed, the two generators will be connected with the circuit, and their equalizing wires will be connected

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through the bus E. The current from switch S' passes to the ammeter on the right side of the board through the wires c and d, and the current from switch S passes to the other ammeter through wires c' and d'. The voltmeter V can be connected with either generator by means of the switch s, and also with the busses N and P, as is clearly shown by the wires v v, v' v', v'' v''. Under the ordinary running conditions, the voltmeter is connected with the busses, and the switch s, when turned to make this connection, disconnects the wires leading to the two generators. If one generator is running, and it is desired to throw the other into service, it must be set in motion and its voltage brought up to equality with that of the running generator before its main switch is closed. Suppose the right-hand generator is in use, and that we desire to start up the other one, then we set it in motion and move the voltmeter switch s so as to connect alternately with each generator, and when both show the same voltage, the S switch is closed.

The main switches S and S' connect the generators with the lower set of busses, but if the switch S'' is open, the current cannot pass to the external circuit. When this switch is closed to the left side, as shown in the diagram, the current from bus N will pass to the top and bottom busses of the upper set, and the current from the P bus will pass to the center bus of the upper set. With this connection, therefore, the current will pass out to the external circuit through the center bus and return to the two outside ones. The object of this arrangement is to render it possible to operate the lamps or other apparatus upon the circuit from the street mains as well as from the generators. The street service being arranged upon the three-wire system,

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the circuits supplied through the S' switch must be arranged for three-wire distribution. Should it become necessary to shut down the generators for any reason, all that would be required to connect the system with the street mains would be to throw the S'' switch over to the right side, and then the three street mains would be connected with the three upper busses, each main being connected with a separate bus bar.

In the diagram, Fig. 18, no circuit breakers are shown, owing to the fact that in this case the generators are protected by simple safety fuses. These fuses can be mounted upon the switchboard or at any other convenient point; but when upon the board they are placed behind and not in front, as they are not attractive in appearance, and when they act they are liable to deface the surrounding parts by covering them with molten metal unless they are of the enclosed type. It is very seldom that a board is arranged so as to depend wholly upon safety fuses—a regular magnetic circuit breaker is invariably provided in the most modern installations. A magnetic circuit breaker is more effective than a fuse for sudden rises of current strength, as it will act instantly, while the fuse will not respond to a sudden rise in current strength if it lasts only for an instant, owing to the fact that it requires some time for a current to heat the fuse wire up to the melting point. Fuses are relied upon almost exclusively for the protection of branch circuits, but for the main line the proper thing is the magnetic circuit breaker.

In Fig. 18 the circuit connections are such that the distributing system can be fed from the two generators, or from the street mains, by turning the switch S'' in one direction or the other. When the street connection is not

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made, the arrangement is somewhat modified. The most simple arrangement is that in which the generators feed into a single distributing system. A switchboard adapted to meet this condition is shown in Fig. 19. Of the three bus bars, the lower one, marked 3, connects with the main switches S_1 and S_2, and through wires $d\,d'$ which will be recognized at once as the equalizing wire, that is, wires $d\,d'$ together with bus 3, constitute the equalizing wire. These equalizing wires, as will be noticed, do not connect with the circuit breakers c b, and it is not necessary that they should; for if the connection with wire e and h is broken the circuit through the generator will be opened.

In this arrangement we have shown each generator connected with its own ammeter, but in some cases only one instrument is used, and this is arranged so as to measure the combined current of the two machines. When such an arrangement is adopted it is common to provide a switch by means of which the ammeter may be connected with each generator independently, when desired, so that the strength of each current may be determined. While we have shown two ammeters in Fig. 21 we have only provided one voltmeter, and this is arranged to indicate the voltage between the two busses 1 and 2. When a single voltmeter is provided, it is arranged so as to be connected with each generator independently so as to be used in adjusting the machines in the act of starting. Only two distributing circuits are shown in this diagram, but it will be noticed that, in one, a circuit breaker is provided as well as a switch. It is customary to provide circuit breakers in the distributing circuits when there are devices upon them that would be seriously injured by an excessive current.

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For two generators.

Fig. 19 shows the simplest form of switchboard for two generators, as it is arranged for only one system of

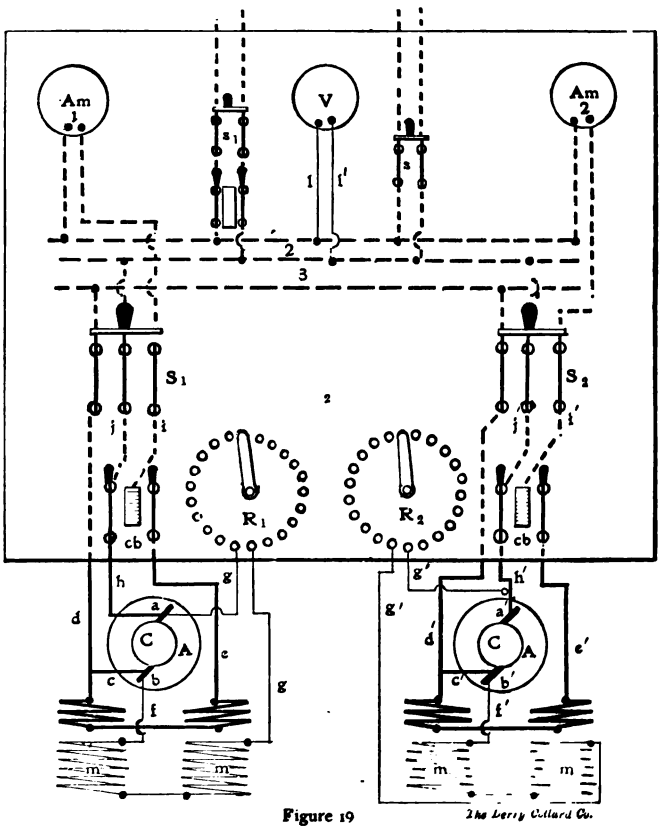

Figure 19 The Derry Collard Co.

Switchboard in which the street connection is omitted.

distributing circuits. In Fig. 20 a more complicated arrangement is shown in which two independent distributing

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systems are provided for. It will be noticed that this diagram is simply an elaboration of Fig. 12, and that two double throw main switches, *S*1 and *S*2, are provided instead of one, but these are necessary on account of there being two generators. In all other respects the diagrams are identical. The main switches in Fig. 20 are shown in the position that connects the generators with the lower set of busses, marked *A*. If either switch is thrown to the opposite side it will connect its generator with the top busses *B*. Both generators can be connected with the top busses and either one can be connected with either set of busses, but the whole system cannot be tied together as in Fig. 12. To accomplish this result we would have to provide a switch to correspond with *s s* of that figure, that is, a switch to connect the two sets of busses. If each generator is connected with a separate set of busses, we can run them at different voltages, but if both feed into the same set as represented in the diagram, the voltage must be equalized. Therefore, unless the two voltmeters indicate the same pressure, the generators cannot be connected with the same set of busses.

In starting up two generators, connected in parallel, the course of procedure is to set the machines in motion, then close the circuit through one and adjust its voltage by means of the field regulator to the proper point. This much being done, the circuit breaker of the second machine is closed, and then the voltage developed by the armature is indicated notwithstanding that the main switch is opened, for the circuit between wires *d* and *e* will be closed through the voltmeter and the wires *j* and *i* leading to the ammeter. By moving the field regulator of the second machine, its voltage is brought to the same

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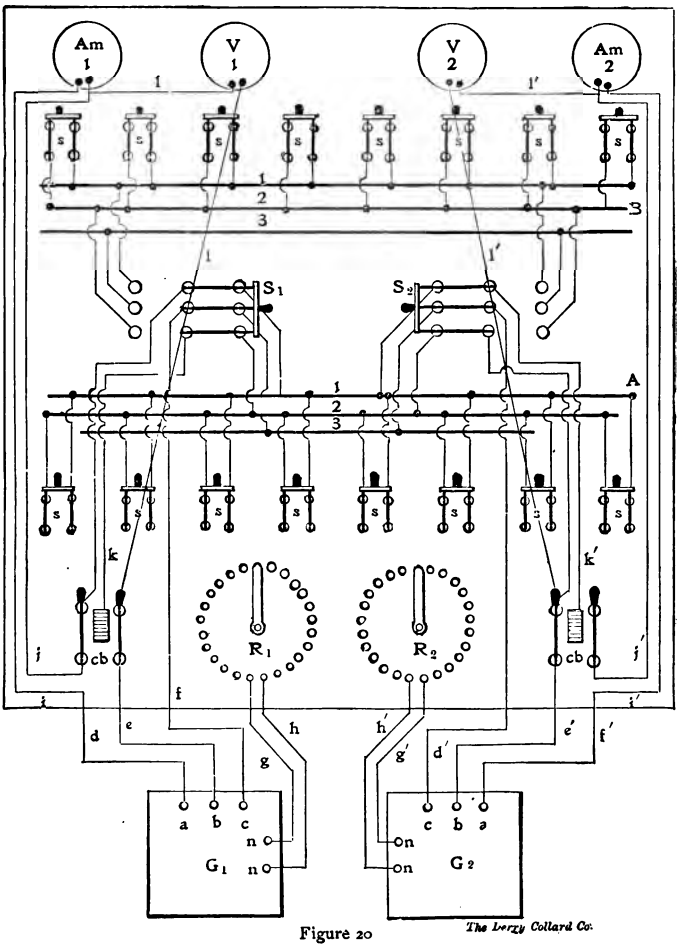

Figure 20

Switchboards arranged for two independent distributing circuits.

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point as that of the machine already in operation, and when the two machines are at the same voltage the main switch of the second one is closed. If the switch of the second generator were closed when the voltage of the first machine was higher than the second, then the latter might be overpowered, and the current could be forced through it in the backward direction if the difference in the voltages were great enough. Under such conditions, the second generator would act as a motor and possibly drive the engine at a speed high enough to do damage. If the second machine were developing the higher voltage when they were connected, it might reverse the current through the first one, and convert it into a motor. Unless the difference in the voltages is very great there is no danger of such an occurrence, for as soon as the overpowered machine begins to lose its current the speed of the engine will increase, and thereby increase the voltage and thus check the further decrease of current, but it is not wise to bank on such action taking place, although it would in most cases. The safest plan is to take it for granted that if the two generators are not adjusted to the same voltage within say one or two volts, they cannot be connected in parallel without doing damage. When only one voltmeter is provided, as in Fig. 19, it must be shifted from one machine to the other to adjust the voltages in starting up the second machine, and this takes time, and is not so reliable a method as when each generator has an independent instrument. Hence, if economy dictates the reduction in the number of instruments, it is better to provide one voltmeter for each generator and only one ammeter for the two. The best arrangement of all, is to provide a differential voltmeter, to be used for the purpose of connecting the generators

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with the circuit. One such instrument will answer the purpose for any number of generators. When a differential voltmeter is used it is connected with the bus bars and with the generator that is to be started and the two voltages act against each other. When they are equal the actions neutralize one another, and the instrument indicates zero.

In Figs. 21 and 22 two arrangements are shown for connecting four generators in parallel so as to feed into a number of distributing systems. In the arrangement of a switchboard the effort should be to make the connections as simple as the requirements of the case will permit, but at the same time we must not follow the course of obtaining simplicity by sacrificing points of vital importance; that is, we must not make the connections such that they do not fully accomplish all that is desired. Now, it may happen that we have a building in which it is desired to arrange the circuits so that the current may be turned off a certain portion at a certain hour and that we be able to turn it off from the switchboard. If such be the case, the connections must be such as to enable us to accomplish the result. Again, it may be required to control the lights in several parts of the building from the board, and the switches and connections must be so made that we can control them. Many other reasons may arise that will interfere with the simplification of the switchboard to the greatest possible extent; therefore, it is necessary to know how to proceed when complicated cases present themselves, and the best way to reach this proficiency is by the study of arrangements calculated to meet more or less complex requirements.

Figs. 21 and 22 are cases of this kind, and being ar-

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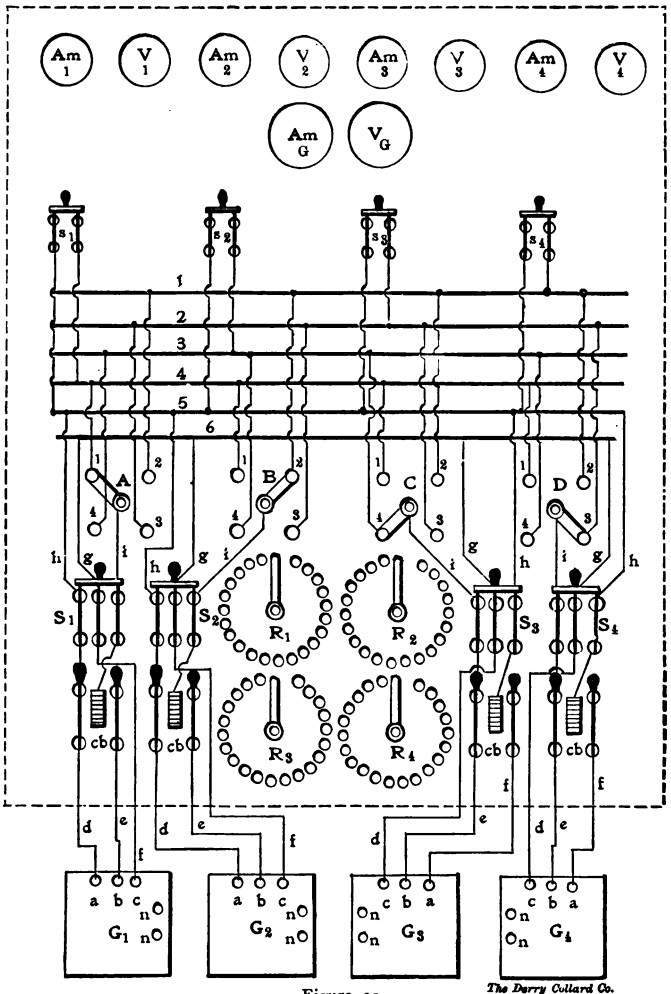

Figure 21

Four generators in parallel to feed a number of circuits.

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ranged differently, a study of them will serve to throw light upon the subject, and to enable us to decide what combinations can be most advantageously applied in any particular instance.

In Fig. 21 four generators are provided to feed into four external distributing systems, and they are so arranged that any one of the generators can be connected with any one of the distribution systems. The way in which all this is accomplished can be made clear by the explanations that follow:—

The four generators G_1, G_2, G_3, G_4 are connected with the four switches S_1, S_2, S_3, S_4, respectively. The wires marked *g* leading from the center contacts of the switches connect with the bus marked 5. Bus 6 is the equalizing bus, and it will be noticed that, as in other diagrams previously presented, the wires that connect with it do not lead from the circuit breaker *c b*. Bus 5 may be the common junction for all the negative, or all the positive wires coming from the four generators. The remaining contact of the *S* switches is connected with the switches marked *A B C D*, by means of the wires marked *i*. These last named switches are of the type called four point, that is, they have four contacts marked 1 2 3 4, and the switch lever, which is pivoted in the center, can swing around so as to make contact with any one of the four points. Each one of the contacts of these four switches is connected with a different bus bar. Thus contact 1 connects with bus 4 and contact 2 with bus 1, contact 3 with bus 2 and contact 4 with bus 3. With the levers of these switches set as in the diagram, generator *G*1 feeds into busses 6, 5 and 4, and as bus 6 is the equalizing bus, the current is taken off from busses 5 and 4. The small dis-

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tributing switch *si* is connected with these busses; hence it is supplied with current from generator *G*1. Generator *G*2 connects, through switch *B*, with busses 6, 5 and 1; hence it will feed into switch *s*4, which is connected with busses 5 and 1.

In the same way as described in the foregoing, it will be found that generator *G*3 feeds into the distributing circuit controlled by switch *s*2, and that generator *G*4 supplies the circuit controlled by switch *s*3. If it is desired to connect two of the generators, as, for example, *G*1 and *G*2, with the same distributing circuit—say with the one controlled by switch *s*3—then the four-point switches, *A* and *B*, are set with their levers covering contact 3. In the same way any of the generators can be set so as to feed into any of the busses. Hence, we have in this construction of switchboard an arrangement whereby any one, or all, of the generators can be connected with any one of the distributing circuits, but we cannot connect any one generator with more than one circuit at a time. If we desire to so modify the arrangement as to render it possible for the generators to feed into more than one circuit at the same time, all we have to do is to provide switches that will enable us to connect the various busses. Thus, if by means of a switch we connect busses 1 and 2, then generator *G*4, with the lever of the *D* switch set as in the diagram, would feed into the circuit controlled by the switches *s*3 and *s*4. Switches used to connect the bus bars are called tie switches, and, as can be readily seen, it is a simple matter to so arrange them as to make any connections desired. By means of one tie switch we can connect busses 1 and 2, and by means of another we can connect busses 2 and 3, while a third tie switch will con-

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nect busses 3 and 4. Thus, by the use of three tie switches we can connect all the busses from 1 to 4, and then we will have an arrangement that will be precisely the same as those shown in previous figures, with only three busses, under these conditions, for the four connected busses would virtually act the same as one.

If we desire to make the bus-tying arrangement more complete, so as to be able to tie 1 and 3, or 1 and 4, or so as to be able to connect any pair without connecting the others, then the switches will have to be more than three—providing two-pole switches are used—and their connection will involve more complication. By using three-point switches of the same type as *A*, *B*, etc., and providing one for each bus bar, we can connect the bars in any order desired; for suppose we provide four such switches and connect the center of each one with one of the busses, then, by placing the lever over any one of the three outside contacts, we can connect with any one of the other busses.

There is one objection to the arrangement of Fig. 21, and that is that the several distributing systems are not entirely independent, but, on the contrary, all are connected through busses 6 and 5. Now, it is desirable, when the external circuits are divided into several systems, to have these entirely independent, so that if anything goes wrong with one set of circuits it will not interfere with the operation of the others. When the several systems are partially connected, as by the busses 5 and 6 in this figure, it is possible for a ground or short circuit in one to interfere with the operation of the others; hence, if each system is so arranged as to be disconnected entirely, the operation will be more satisfactory.

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Twelve switches here.

Fig. 22 shows an arrangement whereby four generators are connected so as to feed into four entirely independent distributing systems; but in this case none of the generators can connect with all the bus bars. Two of them can be connected with three sets of busses, but the others can only connect with two sets. It will be seen that generator *G*1 connects with switch *S*1 running to the center row of contacts, which is marked *k*. This switch is of the double throw type, and when turned to the right connects with the center row of contacts of Switch *S*2. The right-side row of contacts of this switch connect with the busses *C*. Thus, with the switches in the position shown, generator *G*1 is connected with busses *C*. If switch *S*2 were turned to the left, the generator would be connected with the *B* busses. If switch *S*1 were turned to the left, the generator would be connected with the *D* busses. By means, therefore, of the two switches *S*1 and *S*2, generator *G*1 can be connected with either one of three sets of busses—namely, *B, C, D*. In like manner generator *G*2 can be connected with busses *A B C* by means of switches *S*4 and *S*5.

Generator *G*3 is connected with switch *S*6, and when the latter is turned to the left, the generator is connected with the *B* busses, and when turned to the right, it is connected with the *A* busses. By means of switch *S*3, generator *G*4 can be connected with the *C* and *D* busses, it being connected with the *C* set as drawn.

With the arrangement of Fig. 22 it would be necessary to have twelve switches to be able to connect each generator with any one of the busses, and to tie the busses all together four more switches would be required. To be able to connect any set of busses with any other set, or with all of them these tie switches would

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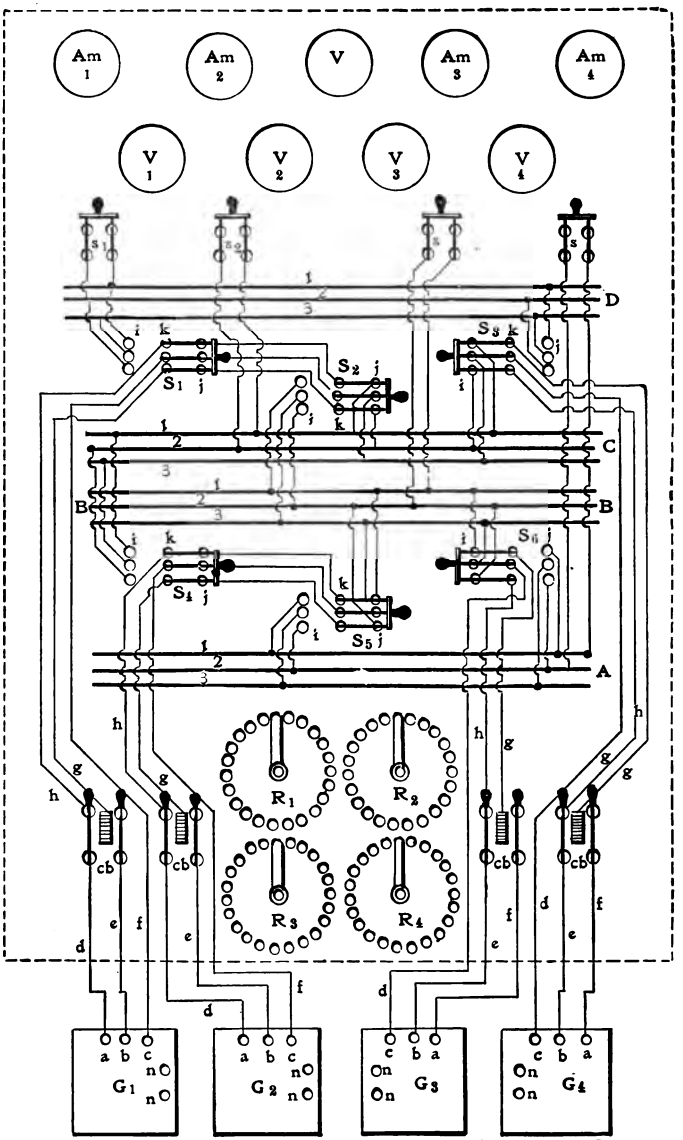

Figure 22

Another arrangement for four generators and four circuits.

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have to be of the same type as *A C D* in Fig. 21; but, as they would have to connect three busses with three others, they would require three times the number of contacts, and on that account would be of a much more complicated construction.

Suppose that generator *G*1 were connected with the center row of contacts of switch *S*2, instead of with *S*1, and that the right-side contact of *S*2 were connected with the center of *S*3 and the left-side row with the center of *S*1, then by turning switch *S*2 in opposite directions generator *G*1 could be connected with the center of either *S*1 or *S*3. If the right and left hand sides of switch *S*1 were connected with busses *C* and *D* respectively, and the sides of *S*3 were connected with busses *A* and *B*, by means of these three switches, generator *G*1 could be connected with any one of the four sets of busses, but only with one set at a time. From this explanation it will be seen that three switches are required to connect one generator with the four sets of busses; hence for the four machines twelve switches would be necessary.

Comparing Figs. 21 and 22 we see that in the first only eight switches, four *S* and four four-point, are required, and only six bus bars, while to effect the same combinations with Fig. 22 twelve switches and twelve bus bars are necessary. From this fact it would at first thought be inferred that the arrangement of Fig. 21 is better than the other, but such is not necessarily the case. It depends wholly upon what we want to accomplish. Fig. 22 is more complicated and more expensive than Fig. 21, but to compensate for the greater expense and complication we have the fact that the four sets of busses are entirely

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disconnected from each other, and no possible disorder of one set could affect the other three. In order to obtain the greater simplicity of Fig. 21 we are compelled to adopt a type of connection in which the four sets of busses are merged into one, and, although by means of it we are able to feed into four separate distributing systems, these are not entirely disconnected, but, on the contrary, all have the busses 5 and 6 in common, and on that account a disarrangement of one set of circuits might result in disabling the whole system.

When the location of the circuit wires is such that the liability of disarrangement is slight, the plan of Fig. 21 can be used, and it is particularly desirable if we wish to reduce the cost of construction to the lowest point. If the circuit wires are so located that there is more or less danger of their becoming crossed, short-circuited, etc., then the construction of Fig. 22 is the proper one, even if we desire to practice economy.

The connection of the measuring instruments, ammeters and voltmeters with the generators is not shown in Figs. 21 and 22, as it would lead to unnecessary confusion; but from the illustrations of instrument connections furnished in other figures, the manner in which the wires should be run can be readily understood when the office of each instrument is explained, as we propose to do in the following lines:

In Fig. 21 the four ammeters—marked *Am*1, *Am*2, *Am*3, *Am*4—are to be connected with the four corresponding generators, and so are the four voltmeters. The ammeters can be connected in series in the *e* wires or in the *d* wires of generators *G*1 and *G*2, and the *f* and *e* wires of the other two machines. The voltmeters

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are connected to the *d* and *e* wires in the two first generators and to *e* and *f* in the third and fourth machines. The ammeter marked *AmG* is intended to be used when all the circuits are connected by means of tie switches into one system, and the voltmeter *V G* is used under the same conditions.

With the latter arrangement of circuit—that is, with busses 1, 2, 3 and 4 tied together—the voltmeter *V G* is connected with one side to bus 5 and the other side to any one of busses 1, 2, 3, 4. The ammeter *AmG* cannot be connected in the circuit with the connections shown in the diagram, for there is no way in which it can be arranged so as to be traversed by the entire current of the four machines. To be able to connect it, it is necessary to provide a seventh bus, to which the wires leading from the generators to bus 5 are attached, or else those leading from the *S* switches to this same bus. The ammeter is then connected between the seventh bus and bus 5, and thus all the current generated by the four machines has to pass through it to reach the distributing circuits.

In Fig. 22 there are four ammeters, one for each generator, and four voltmeters, just as in Fig. 21; but we have no general ammeter and voltmeter, and, as will be seen, it would complicate the circuits to a considerable extent to provide them, for then we would require busses to which one of the wires of the generators could lead, so that between these and the main busses the ammeter could be placed, and also so that the voltmeter could span across from one side of the general system to the other. The circuits could be arranged so as to use a single instrument to indicate the voltage when all the busses are connected into one system, and another in-

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strument to measure the whole current; but as to the voltmeter, the additional complication would not be necessary, since any one of the four voltmeters already connected with the circuit would serve the same purpose. The voltmeter *V*, located in the center of the top row, is what is commonly called a ground detector, and is simply an instrument provided to test the insulation of the circuits before the current is turned on. The ground detector is not kept in service all the time, but is generally connected permanently either to the ground or to the circuits and is provided with a small switch, by means of which the other side may be connected whenever it is desired to make a test. If the permanent connection is with the ground, then the switch makes the connection with the circuit, and then if there is a leak in the insulation at any point, the fact will be revealed by the movement of the indicator of the instrument.

The switchboards we have discussed so far are arranged for the simple two-wire system, which is the one generally used for wiring buildings provided with a lighting plant; but for distribution from central stations, and also for large isolated plants, where the current is conveyed to a considerable distance, the three-wire system is used, and this will be explained in the next section.

A distributing circuit can be arranged for the three-wire system if we have two generators or any multiple of two, but it cannot be obtained with a single machine. If we have only two machines, the switchboard becomes a simple structure; but if there are four, six or more machines, then there will be more or less complication, for we will have to divide the generators into two groups, each one of as nearly the same ampere capacity as pos-

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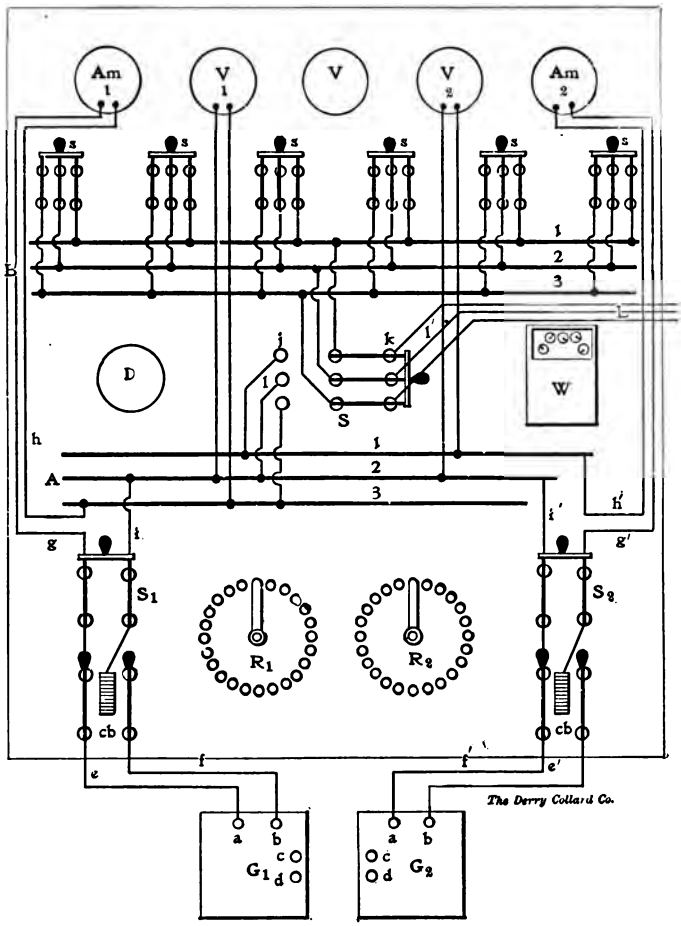

Figure 23

Switchboard with two generators feeding a three-wire circuit.

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sible; and each one of these groups will have to be connected with an independent set of bus bars, so that the machines may be properly equalized. From these two sets of busses, connections will have to lead to the main distributing busses with suitable switches, cut-outs, etc. By explaining simple arrangements, the course of procedure in more complicated cases can be better understood. We will, therefore, start with the consideration of the board presented in Fig. 23, which is arranged with two generators connected so as to feed into one system of distributing mains.

As will be noticed, the generators are not provided with terminals for equalizing wires, none being required. Generator *G*1 connects by means of wires *e* and *f* with the circuit breaker *c b*, which latter connects with the lower contacts of the switch *S*1. The upper contacts of this switch connect with bus bars 2 and 3. The wires *g* and *h* lead to the ammeter *Am*1. Generator *G*2 connects with switch *S*2 and with busses 1 and 2, a connection being made with ammeter *Am*2 by means of wires *g'* and *h'*. As will be noticed, both generators are connected with bus 2, and, while the *f* wire of the first machine connects with this bus, the *f* wire of the second one connects with bus 1. In the same way the *e* wire of the first generator connects with bus 3, but the *e* wire of the second one connects with bus 2. This latter bus, therefore, is the neutral-wire bus.

Voltmeter *V*1 connects with busses 3 and 2, and voltmeter *V*2 connects with busses 1 and 2. These two instruments indicate the voltage between the neutral wire and the side of the system with which the generators they indicate are connected. The third voltmeter *V*, is con-

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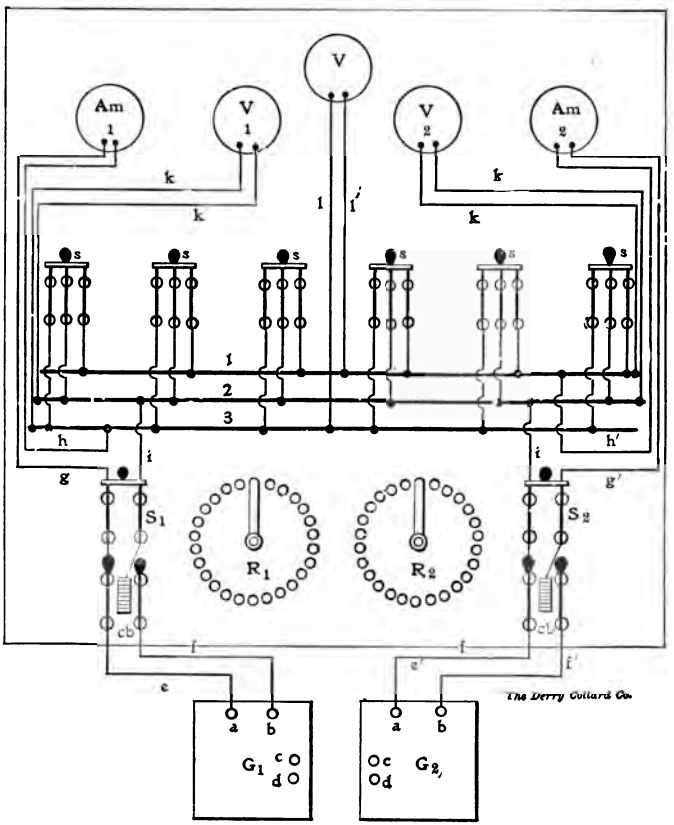

Figure 24.

A simple arrangement for two generators on a three-wire circuit.

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nected across from bus 1 to bus 3, and thus serves to show whether the generators are properly connected. If they are, the volts indicated on this instrument will be twice as great as those of the other voltmeters, or to be more accurate, they will equal the sum of the other two readings. If the generators are not properly connected this third instrument will indicate a zero voltage, or the difference between the readings of the other two instruments. By means of the switch *S* the distributing circuits can be connected with the street supply.

When there are more than two generators they can be connected into a three-wire system by dividing them into two sets of equal ampere capacity. If we have three generators they cannot be connected into a three-wire system, unless one machine has double the capacity of the others, that is, in amperes. If there are four machines, these can be divided into two sets of two machines, and each set can be connected with equalized wires to an independent set of bus bars, and then these two sets of busses can be connected with a third set according to the three-wire system.

In Fig. 23, the lower set of busses can be dispensed with by running the connections from the generators directly to the left side contacts of switch *S*, making the same connections as are made with the bus bars.

Fig. 24 shows the simplest form of three-wire connections, being arranged for two generators to feed into a single distributing system and without street connection.

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Diagrams of Boards in Actual Service.

In the foregoing sections we have explained the way in which switchboards are connected for single generator and multiple generator plants, and also for the three-wire system. The diagrams given are imaginary, with the exception of Fig. 18, and are so arranged as to present the subject in the clearest light, and also so as to indicate as far as possible the modifications required to meet given conditions. In this chapter we will give the diagrams of connections of boards in actual service, and thus show the requirements that have to be met in actual practice, and also the way in which they are met by different designers.

Fig. 25 is a diagrammatic view of the switchboard of the Crescent Steel Works, Pittsburg, Pa. It is arranged to connect two generators of a capacity of 1,000 amperes each and 250 volts electromotive force so as to distribute into a system of circuits, twelve of which are controlled directly and independently from the board, the others being also controlled from the board, but not independently. The two generator circuits and the twelve distributing circuits are provided with magnetic circuit breakers, which also act as switches. These circuit breakers are of the two-pole independent action type. They are called two-pole because they open the circuit on both sides; thus if the circuit breaker directly above the left-hand generator is opened it will break the connection between the board and the two wires running to the generator, one to the left side

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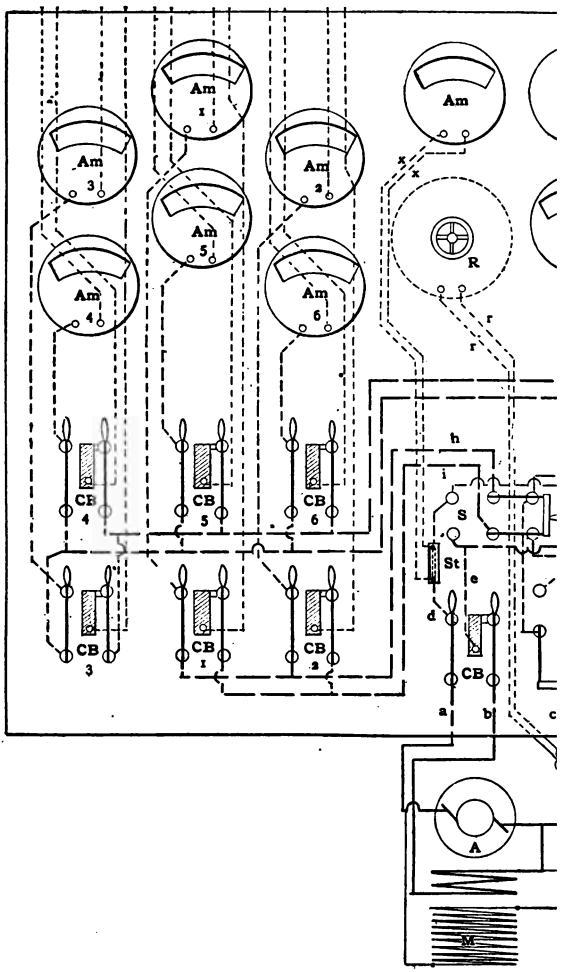

Switchboard at Crescen

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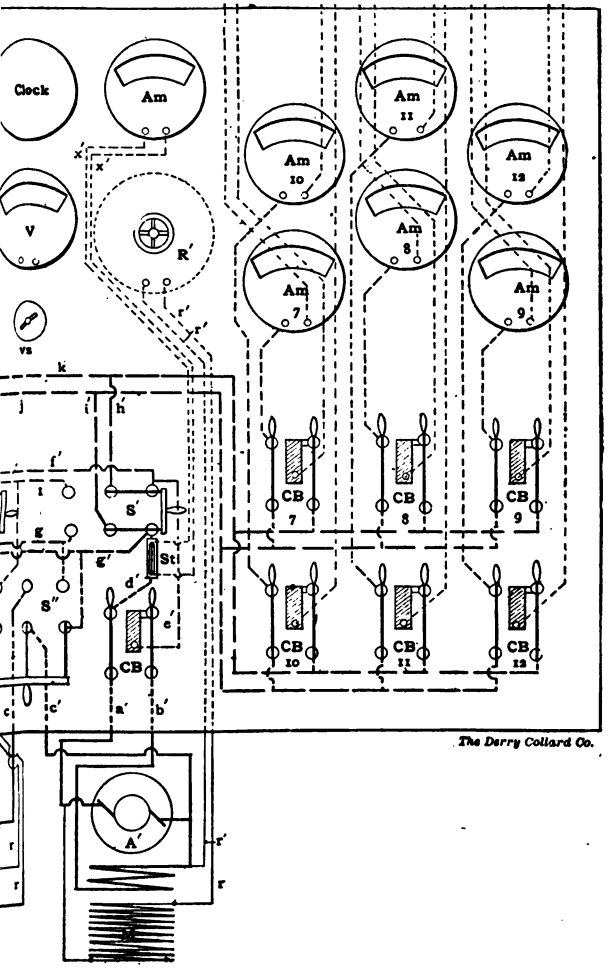

Figure 25.

nt Steel Works, Pittsburg, Pa.

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brush and the other to the end of the series coil. The two sides of the breaker act independently of each other, and to close the circuit one side is closed at a time; hence the name "independent action." A circuit breaker cannot be used as a switch if it is not of the independent action type. By means of the switch *S* the generator on the left can be connected with the conductors *h i*, and by means of the switch *S'* it can be connected with *j* and *k*. As will be seen, *e* connects the center contact of the circuit breaker with conductor *g*, and *d* connects the top contact with conductor *f*. Therefore, if the *S* and *S'* switches are thrown to the left *S* will close the circuit between *f* and *h* and between *g* and *i*, while *S'* will close the circuit between *f* and *k*, through *h'*, and between *g* and *j*, through *i'*. When the *S* and *S'* switches are turned to the right, as shown in the diagram, the left-hand generator is cut out of the circuit, and the other one is cut in. If *S* is turned to the right and *S'* to the left the left side generator will feed into the conductors *j k*, and the right side generator will feed into conductors *h i*. The conductors *h i* lead to circuit breakers 1 and 2, and the conductors *j k* lead to circuit breakers 3 to 12, inclusive. Therefore, by throwing the *S* and *S'* switches in one direction or the other either generator can be connected with either set of circuit breakers; but whichever way the switches may be thrown both generators will be entirely independent of each other, and on this account no equalizing connection is required for this position. When it is desired to operate both generators together the switch *S''* is closed, and then the center blade of this switch connects the conductors *c* and *c'*, which come from the equalizing terminals of the two generators. The left side of the switch con-

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nects f with f', and the right side connects g and g'; thus through this S'' switch the two generators are properly connected to run in parallel with the equalizer connection closed. As the office of the S'' switch is to join the two generators it is called a "bus junction" switch.

From the foregoing explanations it will be seen that either one of the generators can be connected so as to feed the circuit $h\ i$ or $j\ k$, or both, and that one machine can take part of the load while the other takes the balance; or both generators can be connected to work together, and all this is accomplished by the movement of the three switches S, S' and S''.

The field regulators are placed by the side of the voltmeter V, so that the latter may be watched to note the effect produced upon the voltage of the generator when the regulator wheel is being moved. The two ammeters directly above the field regulators $R\ R'$ indicate the current of the generators, while the other twelve instruments are placed in the twelve branch circuits controlled by the circuit breaker switches. Only one voltmeter is used, and, as in the case of Fig. 18 this is normally connected with the working circuit so as to indicate the voltage of the line, but when the generators are to be thrown into parallel connection it is used for the purpose of equalizing their electro motive forces, the small switch $V\ S$ being provided for the purpose of connecting the instrument with either generator.

In comparing the switchboards illustrated in Figs. 18 and 25, we can see several marked differences; for example, the first is provided with an equalizing bus bar, while the second one is not; nevertheless, both are properly arranged to connect the equalizing wires of the gen-

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erators when the latter are required to operate in parallel relation. In Fig. 25 the center connecting blade of the S'' switch plays the part of an equalizing bus. This arrangement is not adapted to Fig. 18, owing to the fact that the generators are not required to operate separately, but at all times feed into the same system of distributing circuits. Fig. 18 has a double set of bus bars, and before the current can pass to the distributing circuit it is necessary to close the S'' switch; and this is true, whether the current is derived from the generators or from the street mains. Upon examining the diagram it will be found that the second set of bus bars become necessary in order to be able to take current from the three-wire street system. If the S_1 switches were connected directly with the lower set of busses, they would operate well enough when taking current from the street; but when supplied from the generators they would not, for then all the lamps, or motors, connected between the E bus and the top one, P bus, would be practically connected with the same end of the line, and would therefore not receive any current worth mentioning, as the voltage acting upon them would be practically nothing. When the S'' switch is thrown to the left it connects only the top and bottom busses of the lower set with those of the upper set, and as with this connection the center upper bus is the positive side of the generators and the top and bottom busses are the negative side, all lamps connected between the center and either of the two N busses will get the proper voltage when the current is derived from the generators, and also when the street supply is used.

In Fig. 18 the ammeters are connected in the circuit, so that all the current of each generator passes through its

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respective instrument; but in Fig. 25 the ammeters that measure the current of the generators are so arranged that only a portion of the main current passes through them. Tracing the lines x x and x' x' it will be seen that they lead to the ends of blocks marked *St*. These blocks are shunts and are for the purpose of diverting a portion of the current through the ammeter. The twelve ammeters in the branch circuits are arranged as in Fig. 18 so that the whole current passes through them. If we look at circuit breaker switch No. 3 we will find that its top terminal is connected with the No. 3 ammeter, the other terminal of this instrument passing directly out to the external circuit. The other side of this circuit comes down to the center terminal of the No. 3 circuit breaker. The ammeters in the branch circuit are connected so that the whole current passes through them, because they are of small capacity, compared with the instruments that measure the main currents. The connections on switchboards are generally made with bars that have a cross section of 1 square inch for each 1,000 amperes, and from this it can be seen that to connect ammeters of large capacity directly in the circuit would require the use of large conductors. When the shunts *St* are used, the current passing to the instrument need not be more than a small fraction of 1 per cent., hence it can be carried in small wires.

Fig. 26 shows the arrangement of circuit connections and instruments upon the switchboard of the Franklin Building, New York City. This board is one of the best examples of modern switchboard engineering practice. It is arranged to connect three generators with two systems of distributing circuits, one being used for lighting and the other for power. These circuits are also ar-

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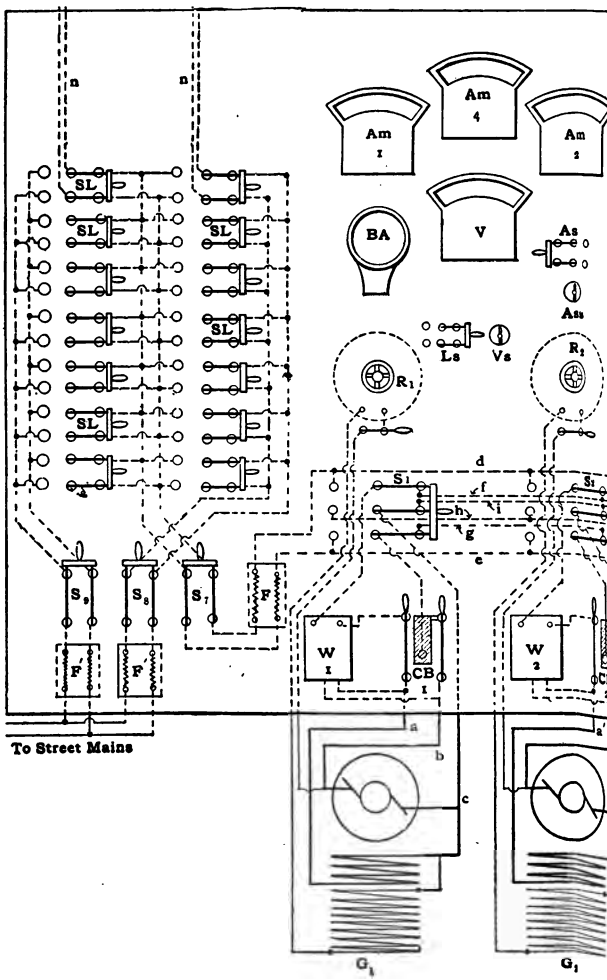

Switchboard in Franklin Bu

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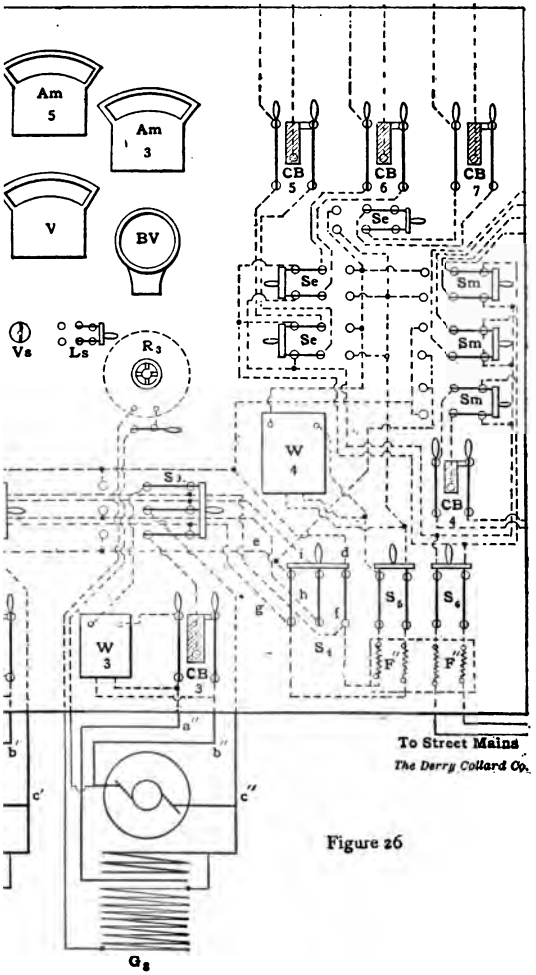

Figure 26

ilding, New York.

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ranged so as to be fed from the street mains, and the connections are such that at any time a part of the system can be operated from the street mains and the balance from the generators. Any one of the generators can be connected with the entire system of circuits, or the power and light portions may be run separately, two generators furnishing current for one part, and the other generator supplying the remainder. The way in which these results are accomplished can be readily understood from the following description:

The three generators are connected with the system in the same order; hence, the description of the connections of one will answer for the other two. Looking at the generator $G1$ it will be seen that the lines *a* and *b* run to the lower terminals of the circuit breaker $CB1$. Line *c*, which is the equalizing connection, runs to the center terminal of the $S1$ switch, directly above the circuit breaker. The center terminal of the circuit breaker is connected with the lower center terminal of the $S1$ switch, and the top circuit breaker terminal connects with the rectangle marked $W1$, which is a wattmeter. From the other terminal of this wattmeter a connection runs to the top center terminal of the $S1$ switch, thus connecting the three center terminals of this switch with the generator terminals.

When the $S1$ switch is thrown to the right side, as shown in the diagram, bus *g* is connected with the center terminal of the circuit breaker, and this, through the right-side lever, is connected with the generator lead *b*. In the same way bus *f* is connected through the wattmeter and the circuit breaker with generator lead *a*, and bus *i* is connected directly with lead *c*. From this it will be

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seen that bus *i* is an equalizing bus. When the S_1 switch is thrown to the left generator lead *a* is connected with bus *d*, and lead *b* with bus *c*, while the equalizer lead *c* is connected with bus *h*. Thus when the switch is thrown in opposite directions it connects the generator terminals with two different sets of busses, and in these two sets *h* and *i* are equalizing busses, while *d* corresponds to *f*, and *e* to *g*.

If we follow the busses *e* and *d* to the left we will find that they run to a rectangle *F*, which is a double pole safety fuse, and from here to a switch S_7. From this last switch lines run up that connect with fourteen smaller switches marked *S L*. Each one of these switches feeds into a lighting circuit, only two of which, marked *n n*, are shown, to avoid confusion. Adjoining the switch S_7 are two other switches S_8 and S_9, and these are connected through the safety fuses *F' F'* with the street mains. Switch S_8 is connected with one row of the *S L* switches, and switch S_9 with the other row. The *S L* switches are of the double-throw type, and when turned in one direction connect the lighting circuits *n n* with the street mains, and when turned in the other direction connect them with the busses *e* and *d*. If the switches S_8 and S_9 are closed, any one of the *S L* switches can be turned so as to take current from the generators or from the street.

If we follow the *e* and *d* busses to the right we will find that they lead to two of the switches marked *Sm* and also to the top side terminals, of the switch S_4. Following the *g* and *f* busses we find that they run to the lower corner terminals of the S_4 switch, and from here to the safety fuse *F''* and the switch S_5. From the upper right-side terminal of the S_5 switch a connection runs to the

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three *Se* switches and also to the top *Sm* switch. From the left-side upper terminal of the S_5 switch a connection runs to the wattmeter W_4, and from this a connection runs to the *Se* switches and to the top *Sm* switch. Thus it will be seen that through switch S_5 and wattmeter W_4 the *g* and *f* busses feed the *Se* switches and one of the *Sm* switches. The street mains, coming in at the right side of the board, lead through switch S_6 to the three *Se* switches, and also to the three *Sm* switches; hence, the circuits controlled by these switches can be fed from the generators or from the street mains. The circuit controlled by the lower *Sm* switch is provided with a circuit breaker, $C\ B_4$, and the three circuit breakers $C\ B_5$, $C\ B_6$, $C\ B_7$ protect the circuits controlled by the *Se* switches. These latter switches are in circuits that operate passenger and freight elevators.

If the switch S_4 is opened, there is no connection between the *d e* and *f g* busses. Therefore, under this condition the three generators can be connected all with one set of busses, or one with one set and the remaining two with the other set of busses. If the S_4 switch is closed, bus *g* will be connected with bus *e*, and bus *f* with bus *d*, while the two equalizing busses, *i* and *h*, will be connected through the center blade. With this connection the three generators will feed into the whole system and the two sets of busses will become practically one set. In each set of busses there is an equalizing connection, so that two or more generators may be connected with that part of the system.

Under ordinary circumstances it is desirable to keep the power and light circuits separate, as the sudden changes in the current taken by the motors tend to un-

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steady the voltage too much for the successful operation of the lights, but by having two parts of the system so arranged that they can be joined into one, it becomes possible to operate the entire plant with greater economy at times when the full capacity is not required. Suppose that at some time a small number of lights were in use on all the various branches of the system, but not enough in the aggregate to absorb more than a portion of the capacity of one generator, and at the same time suppose that the demand in the power circuits were also very low, then if the two parts could be connected in one, a single generator might be capable of doing the whole work, but if each part had to remain separate, two machines would have to be kept in service.

In this installation the wires leading in from the street are only two in each circuit, owing to the fact that the lamps in use are of the 220-volt type; hence, they can be fed from the outside wires of the three-wire street system. As all the *S L, Se* and *Sm* switches are of the double-throw type, any one of the branch circuits can be fed from the street mains or from the generators, and if the switches S_6, S_8, S_9 are kept constantly closed, the change can be effected instantly.

The ammeters 1, 2, 3 are connected with the three generators and are of the shunt type. The ammeter Am_4 is so arranged that it can be cut into any of the circuits leading from the *S L* switches, and thus render it possible to measure the current in these branches at any time. The shifting of this instrument to the various circuits is accomplished by the aid of the switch *Ass,* the switch proper being back of the board, the part seen being simply the handle. The ammeter Am_5 is arranged so as to be con-

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nected in the power circuit or the light circuit, and is controlled by the double-throw switch *As*. The two voltmeters are so arranged that one will indicate the voltage of the power circuit and the other that of the light circuit. When a generator is cut into service one of the voltmeters is used to indicate the voltage of the busses with which it is to be connected, and the other connects with the generator terminals. Thus the two voltages can be equalized before the generator switch is closed.

B A and *B V* are recording instruments, the first being an ammeter and the second a voltmeter. These instruments trace a line upon a cardboard dial, just like a recording steam gauge. The wattmeters W_1, W_2, W_3, W_4 are sometimes called recording wattmeters, but they are more properly called integrating meters, for they indicate the sum total of the electrical energy that has passed through them up to the time of reading. The *Ls* switches are for the purpose of turning on or off the lights that illuminate the switchboard. The voltmeters are controlled by the switches whose handles are shown at *Vs Vs*. The field regulators are shown at R_1, R_2, R_3. The switch seen below each regulator is for the purpose of opening the circuit through the shunt field of the generator, but as there is nothing to be gained by being able to open this circuit, and as it may produce serious results, the introduction of this switch cannot be recommended.

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Construction of Switchboards.

Switchboards designed for plants of small capacity have no particularly interesting constructive features, owing to the fact that small conductors are capable of conveying the current, and these can be made of wire which is readily bent into any desired shape. As a rule the cross section of conductors is estimated so that the current density will be from 600 to 1,000 amperes per square inch. If the capacity of the plant is not over two or three hundred amperes it can be readily seen that the various connections can be easily made by running two or three copper wires of large size side by side. If the electromotive force is 220 volts, which is the pressure most commonly used, the power may be estimated roughly as equal to one horse-power to every four amperes; hence, 200 amperes would represent fifty horse-power. If the capacity of the plant is 500 horse-power, the amperes will be about 2,000, and the cross section of the conductors will have to be from two to three square inches. In manufacturing establishments 500 horse-power is not considered a large plant; in fact, it is smaller than many, the capacity in some instances running up to several thousand. From this it will be seen that in electrical installations such as are required for large manufacturing establishments the currents handled range all the way from, say, 1,000 amperes up to 15,000 or 20,000, and in some cases may go far beyond this point, if the voltage is very low, as is frequently the case where the current is used for

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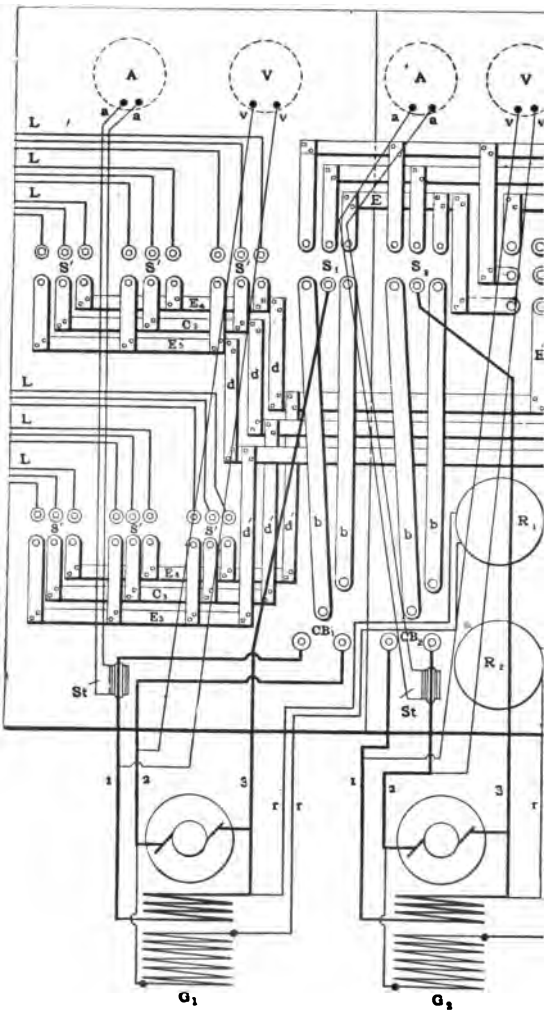

Fig

Back of Switchboard, ar

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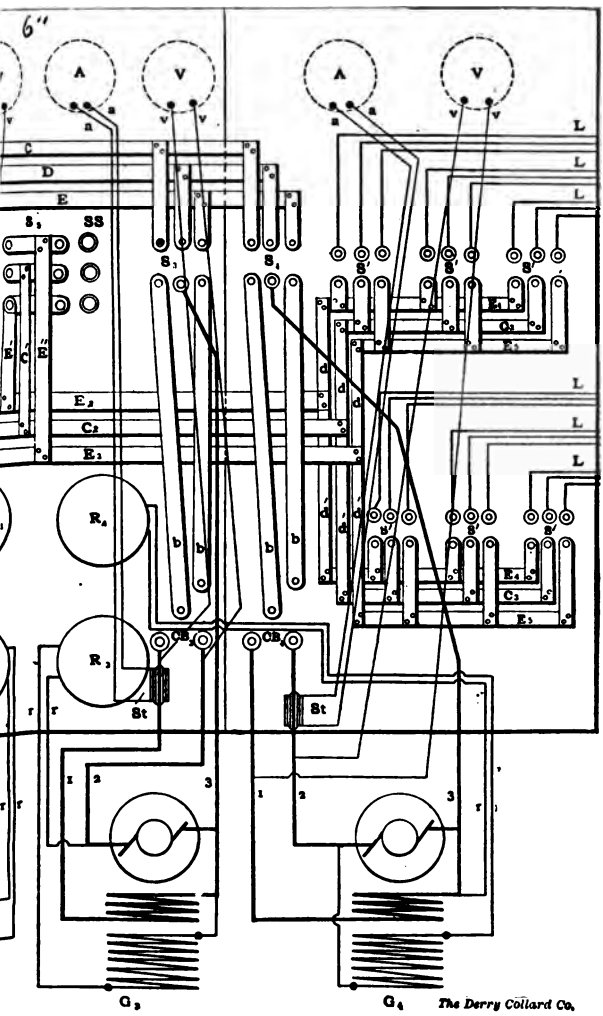

igure 27

arranged for four generators.

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electro-chemical operations. If we estimate the cross section of the conductors at the rate of 1 square inch per 1,000 amperes, then the range of cross sections for the switchboards of industrial installations will be from 1 to 15 or. 20 square inches. Unless the current is used for chemical processes the cross sections will not very often run beyond four or five inches, for when the power transmitted is very great the voltage is increased, and thus the current strength reduced.

For any size of conductor greater than one-half of a square inch, flat bars can be used to better advantage than round wires, and they are more desirable from an electrical point of view, as they present a greater radiating surface for the same cross section, and therefore will not heat up to the same extent with a given current strength. The general arrangement of these connecting bars is shown in Fig. 27, which represents the back of a switchboard arranged for four generators, each one having a capacity of 1,000 amperes, making 4,000 amperes as the total capacity of the board. The connections between the generators and the board are shown in single lines, but these are made with cables, or bars, whichever may be the most convenient. The conductors 1 2, of each generator, run to the lower terminals of circuit breakers, which are marked $C\ B_1$, $C\ B_2$, etc. The conductors marked 3 are the equalizer connections, and run to the lower center terminals of the switches marked S_1, S_2, S_3, S_4. The bar D is the equalizing bus, and the bars C and E are the positive and negative busses, and to these the current passes from the outside terminals of the switches, these being connected with the center and top terminals of the circuit breakers by the bars b b. This board is

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arranged so as to distribute the current of the generators, or to obtain a supply from the street mains. The switch S_5 is for the purpose of connecting the bars E_2, E_3, C_2, which are the main distributing busses, either with the generator busses C E D or with the street mains, which come to the three terminals in the vertical row marked SS. The switch S_5 is double throw, and when thrown to the left connects the generators and the main busses, and when thrown to the right connects the street mains with the main busses. The main busses, at both ends, connect with secondary busses E_4 E_5 C_3 by means of the bars marked d d d and d' d' d'. From these secondary busses the current passes by means of the distributing switches S' to the external circuits L L L.

The ammeters are of the shunt type and derive current from the top and bottom terminals of the ammeter shunts marked St. The voltmeters are connected with the lower terminals of the circuit breakers or with any convenient points on the wires 1 2 leading from the generator. As the ammeters and voltmeters take very small currents, the connecting wires are small flexible cables.

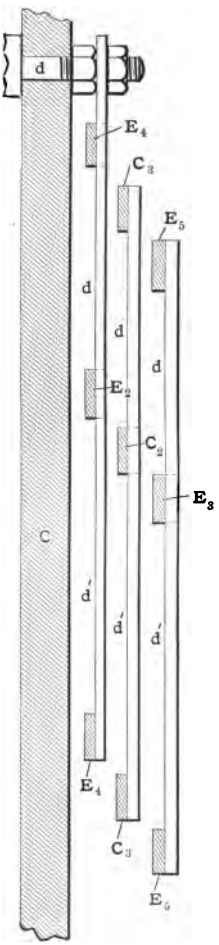

Figure 28.
Cross section showing bus bars.

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Current that must be carried.

As a rule all the connecting bars are made straight and are run at different distances from the back of the board, so that they may cross each other and leave a sufficient intervening space to render accidental contacts improbable. The cross section, Fig. 28, shows the location of the main bus bars E_2, E_3 and C_2, and also of the secondary busses E_4, E_5 and C_3. The position of the connecting bars *d d d* and *d' d' d'* is also shown. Owing to the fact that the different bars are run in separate planes, the studs which form the terminals of the switches and circuit breakers and to which the connecting bars are attached, must be made of different lengths or else be long enough to reach the most distant bars. The latter construction is generally followed, and in order that the studs may be adapted to hold bars at different distances from the back of the board, they are threaded throughout their entire length, and are provided with three nuts, one of which clamps the stud to the board, the other two holding the bar, as is shown in Fig. 29.

The generator busses *E D C* have to carry currents of 2,000 amperes, owing to the fact that the switch S_5 is located at the center. If this switch were placed at one end, then these bars would have to be of sufficient size to carry 4,000 amperes. Thus it will be seen that by properly locating the switches the size of the connecting bars can be reduced. The main busses E_2, E_3 and C_2 are also arranged so that one-half the current runs in each direction; therefore, they need only be of sufficient capacity to carry 2,000 amperes. The bars leading down from *C D E*, and up from E_2, E_3 and C_2, to the throw-over switch S_5 must be of sufficient size to carry the whole current. The bars *d d d* and *d' d' d'*, and also the sec-

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ondary busses, are made of a cross section sufficient to carry 1,000 amperes. From the foregoing we see that the bars connecting with switch S_5 should have a cross section of 4 inches, but as they are very short we can

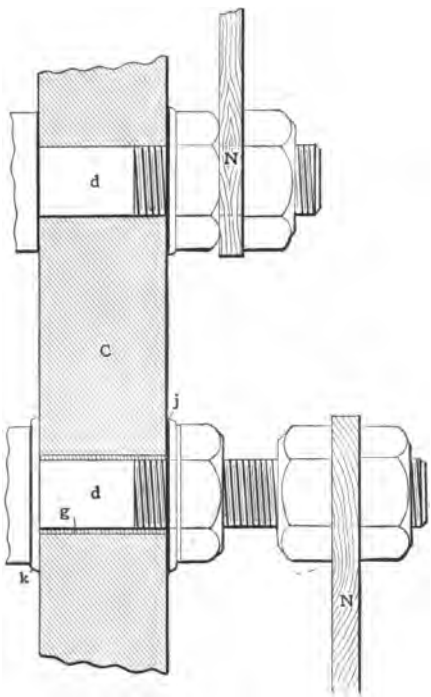

Figure 29. Method of clamping bus bars.

safely reduce it to 3 inches. The generator busses *C D E* and the main distributing busses E_2 E_3 C_2 must have cross sections of 2 inches, and the bars *d d d* and *d' d' d'* and the secondary busses E_4 E_5 C_3 must have cross sections of 1 square inch.

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Radiating heat of current.

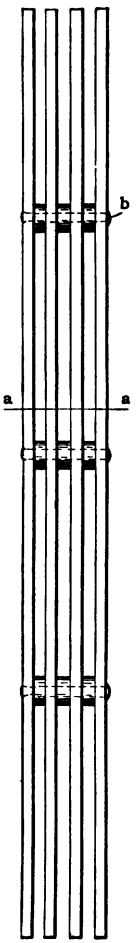

Figure 30.
Increasing radiating surface.

When the cross section of the bars is small they are made of a single bar, but when the cross section is large they are generally built up of several thin bars separated from each other as shown in Figs. 30 and 31, the latter being an enlarged section through *a a* of the former. This construction is resorted to for the purpose of reducing the cross section. When the current to be carried by a conductor is small the size of the bar required may be too small to give the necessary stiffness, and on this account the carrying capacity is estimated at the lowest limit, but when the current is large there is no lack of mechanical strength, and then as the size of the bars begins to seriously increase the cost of the structure, the carrying capacity is estimated at the highest limit. For example, if the current is, say, 500 amperes, the bars may be calculated on a basis of 600 amperes to the square inch of cross section, but if the current is 4,000 amperes the bars will be estimated on the basis of 1,000 amperes per square inch. In the latter case the increased current density will result in generating more heat, and in order that the temperature of the bars may not rise to such a degree as to materially increase the electrical resistance they are laminated so as to increase the radiating surface; hence the construction shown in Figs. 30 and 31.

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Laminated bus bars.

If Fig. *27* is closely examined it will be found that all the bars are supported by means of the connections made with each other and with the terminals of the switches and circuit breakers. Thus the generator busses *C D E* are held by the connections with the four main

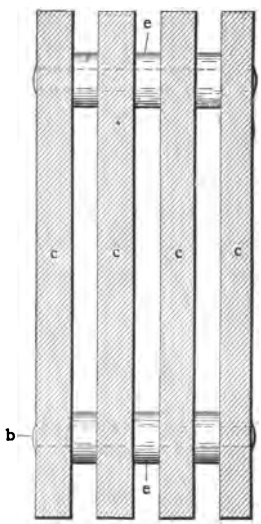

Figure 31.
Increasing radiating surface by laminating.

generator switches and the connections with switch S_5. All the other busses and connecting bars are held by means of the connections with the distributing switches *S'*, and also by the connection with the switch S_5, this latter attachment serving as a support for the center of the busses E_2, E_3 and C_2. The effort of the designer should be directed toward so disposing the switches and instruments with which electrical connections have to be made

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that these connections will afford all the support the connecting bars require. There are very few instances in which a skillful designer cannot accomplish this result without in any way interfering with the proper location of the several devices. But when it becomes necessary to provide additional supports these must be of such a character as to insulate the bar from the switchboard, not only from the metallic parts thereof, but also from the slate or marble slabs which constitute the surface, although attachment to the marble slabs without insulation may be made if the voltage is not over 110 and the installation is of small capacity, say, under 100 horse-power. Marble and slate are generally good enough insulators to hold the circuit connections without further insulation, providing they are dry, but in damp weather their insulating qualities cannot be depended upon. On this account, for voltages over 500 the switch, circuit breaker and instrument terminals should be insulated from the board by means of sheet mica washers and tubes, as shown at *g k* and *j* in Fig. 29.

In Fig. 29 the arrangement of the bus bars and other conductors on the back of the board is such that they can be securely held by means of the bolts that form the connections with the various switches, circuit breakers and other apparatus. There are very few cases in which it is not possible to obtain the necessary support in this way; when, however, this method will not give all the stiffness necessary to prevent the bars from coming in contact with each other by vibrations, or otherwise, they must be additionally supported by means of attachments with the marble slabs or the supporting frame of the latter.

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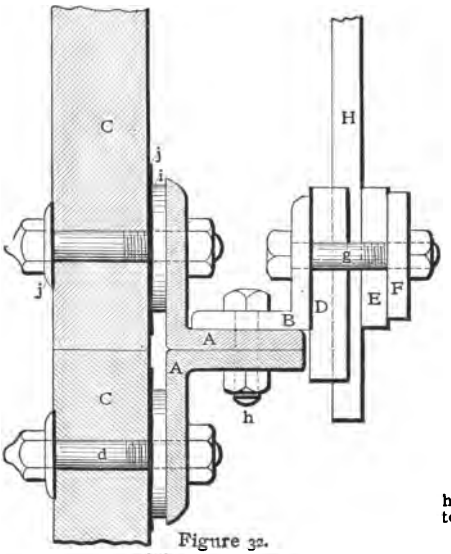

Figure 32.

Designs for holding bars to framing.

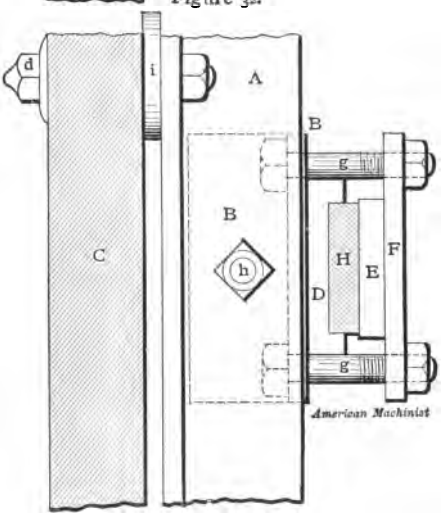

Figure 33.

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Holding conducting bars.

In Figs. 32 and 33 a design is shown for holding the conducting bars from the framing. The first one of these figures is an elevation, showing a section through the conductor *H*, which is in a horizontal position, and the second figure is a plan. In both these figures the conductor is marked *H* and *C* represents the marble slab. The conductor *H* must be insulated from the clamps *B* and *F*, and from the bolts *g*, so that there may be no electrical connection between it and *C* or *A*. Since the object of the insulation is to separate, electrically, *H* from *C* and its supporting frame *A* it follows that if *B* is insulated from the bolt *h*, and from *A*, the insulation between *H* and *B* need not be provided; that is, insulation at one point between *H* and *A* is just as good as at another. The construction shown, however, is the simplest and strongest. Insulation between *H* and *A* is required because *A* is generally not insulated from the ground, and even when it is *A* can be grounded accidentally very easily; hence, if there were no insulation between *H* and *A* there would be great liability of grounding the circuit. In a case where *B* is supported from the marble slab, it might be supposed that the insulation of *H* would be necessary, and it would be so far as *C* is concerned if the voltage were low, but insulation between *H* and *d* would still be required, for the head of *d* is upon the face of the switchboard, and if not insulated from the circuit damage might be done by accidentally connecting it with some of the switches..

If the voltage is not over 110 the insulating blocks *D* and *E* can be made of marble or slate, and be used alone, but for higher voltages sheet mica should be placed between them and *H*. In every case it is advisable to place a layer of asbestos between the clamps *B F*, and the blocks

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D, and also between these and *H*, so that the pressure of the bolts *g g* may be distributed over a greater surface and not be liable to break the insulators. For the same reason it is well to make the surfaces of *D* and *E* cut away slightly around the edges, so that the pressure may be exerted against the center portion.

In some instances the conducting bars are supported from the framing of the switchboard in the

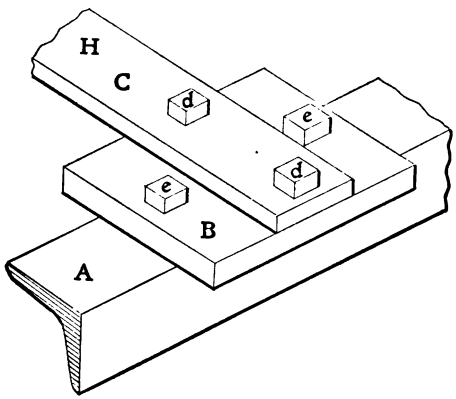

Figure 34.
Another way but not as good as those shown before.

manner shown in Fig. 34, but this construction, as can be readily seen, is not mechanical since *H* is dependent wholly upon the strength of the marble or slate slab *B*. The slab *B* is secured to the framing *A* by the bolts *e*, and *H* is secured to *B* by the bolts *d*. As marble and slate are both brittle, it is not safe to depend upon the slab *B* to hold *H*, for if the pressure of the bolts *e* or *d* should be so applied as to produce a strain the slab might break and allow *H* to fall out of place, and in so doing it

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might short circuit some of the other conducting bars and result in a serious loss.

Since the accidental contact of conducting bars that should be insulated from each other can result in the destruction of the generators, it follows that no construction is proper that is in any way uncertain, and on this account the arrangement of Fig. 34 cannot be looked upon as desirable. It costs less than the design Fig. 33, but in the long run may cost several hundred or possibly thousand times more.

The conductor bars of switchboards are made of copper of the purest kind. Copper castings should never be used unless the pieces are very short, owing to the fact that castings are not made of pure copper, and their resistance is from about one and a half to several times as great as that of the pure metal. The relation between the width and the thickness of the bars has to be determined by the amount of surface required where two bars are joined, and also by the thickness necessary to afford the proper stiffness. A straight bar is made in one piece, but where bends are required they are made by lapping one bar upon another at the proper angle. In some cases it may be found advantageous to heat the bars and bend them into the desired shape, but generally this procedure is not satisfactory, as there is considerable difficulty in handling these crooked pieces when they are entwined with each other on the back of the board. If the points between which the bars are supported are far apart the thickness must be increased to prevent vibration, but bars as thin as ¼ inch may be as long as 4 or 5 feet between supporting points, and if bars that are to be maintained separate from each other are held in position by means of plates of

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glass or porcelain, where they cross each other, the distance between supports can be nearly doubled. When glass or porcelain plates are placed between bars the plates should be of a thickness equal to the space between the bars, and the bars and plates should be securely held by suitable clamps.

When one bar is lapped on another the surfaces in contact should be at the rate of about 1 square inch for each 150 amperes of current for small capacities, and for very strong currents the surface may be reduced to 1 inch per 200 amperes.* Two bars 2 inches wide lapped on each other at right angles will have a contact surface of 4 square inches and will conduct about 700 amperes; therefore, the thickness should be about 3/8 inch, which would give a cross section of 3/4 inch. The contact surfaces should be as true as they can be made without going to the expense of scraped surfaces, and the bars should be held together with iron bolts or screws, the latter being used for small bars. The number of screws should be not less than two in any case, otherwise the joints may twist around and become loose. It is better to use four small bolts than two large ones, as, with the increased number the pressure is more evenly distributed and the contact of the surfaces is made more complete. Iron bolts are better than brass or copper, not only because they are stronger, but also because they do not expand as much as the copper bars with increase in temperature. Therefore, the warmer the joint becomes the more perfect the contact, as the difference in expansion increases the pressure.

The supporting frame of a switchboard is a very simple structure, consisting of vertical angle irons placed at the sides of the board, and intermediate angles located where

* By amalgamating the contacts on bus bars or switches with the Harold Brown process and using a thin layer of Plastic Alloy, the contact surfaces may be reduced to one square inch per 1000 amperes without danger of heating and a permanent joint of very low resistance obtained.

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the marble slabs join. These angle iron bars run down to the floor and thus form the legs of the structure. If the board is so small that it can be made of a single slab

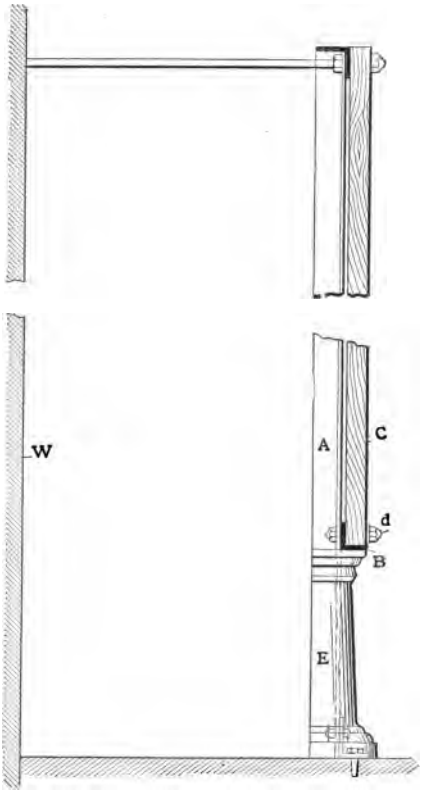

Figure 35.
Another method of fastening.

there will be only two angle bars, one at each side. At the bottom of the board the vertical angle bars are tied together by means of a horizontal bar which is sometimes

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secured in the way shown in Fig. 35, or more clearly in the enlarged detail, Fig. 36, and sometimes as shown in Fig. 37. If the construction of Fig. 36 is used the angle iron cannot be seen, except by its narrow edge, but with the construction of Fig. 37 the angle can be readily seen

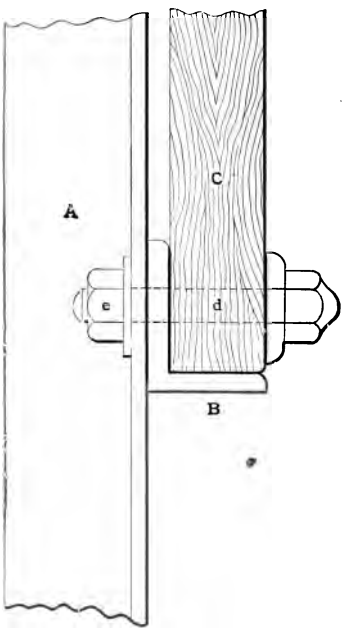

Figure 36. A detail of Figure 35.

from a short distance, as it projects its full width below the marble slab. With the latter construction the marble can be made to rest directly against the vertical angle bars *A*, but with the arrangement of Fig. 36 there will be a clear space equal to the thickness of the side of the

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angle iron, and unless the bar is rolled with sides of uniform thickness it will be necessary to chamfer away the edges of the slab to obtain a bearing anywhere except at the corner. The top of the switchboard frame is finished off with an angle bar run even with the top of the slab. If the construction of Fig. 36 is used the angle is located as in Fig. 35, that is, with one side between the vertical

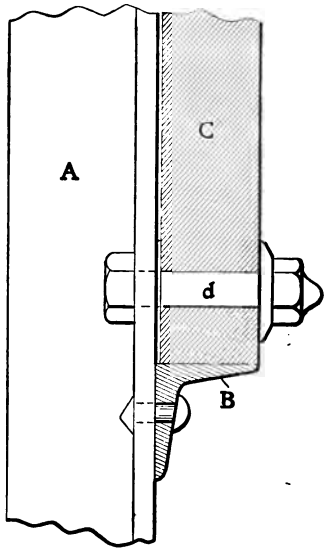

Figure 37. Another detail of Figure 35

angle bars and the slab, and the other side resting on top of the verticals. With the construction of Fig. 37 the top angle is placed so as to rest on top of the slab, and the verticals are carried the width of the angle above the slab.

While angle iron is very generally used for the framing of switchboards, it is not universal. In some instances

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Uprights of I-beams.

I-beams are used for the uprights, the arrangement being as shown in Fig. 38, which represents a plan in section through a beam located opposite a joint in the marble. At the side of the board the I-beam is placed flush with the edges. The use of I-beams cannot be said to be as desirable as the angle iron, because it is more expensive and not so substantial, so far as the slabs are concerned, owing to the fact that the bolt holes must be drilled near

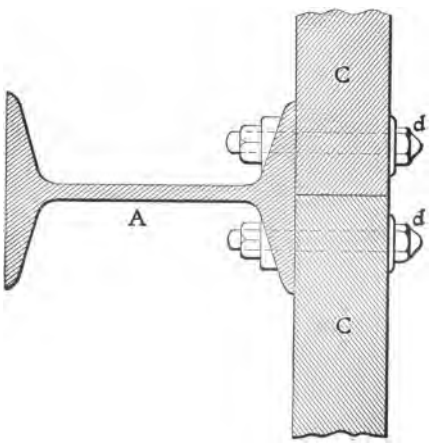

Figure 38.
Use of I-beam in switchboard construction.

to the edges, and, therefore, are more liable to break out.

The bottom of a switchboard should be of such height that the attendant can see the lower instruments or switches without inconvenience, and the top should be of such a height that the highest instruments can be reached from the floor. If space is limited the bottom of the board may not be over a foot and a half from the floor, but two feet should be allowed whenever possible.

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If the board cannot be made of such width as to permit of placing all the switches that have to be handled within easy reach of a man of average stature, then the board should be made in two stories, with a platform from which the device upon the upper part may be manipulated.

The space between the back of the board and the wall should be four feet or more, and if possible the location should be such that there is an abundance of daylight back of the board, so that connections may be made when necessary without the aid of artificial light. Artificial lights should also be provided so as to facilitate work after dark. If there are windows back of the board they should be so arranged that rain and snow cannot enter through them and reach the board, and in damp weather they should be closed tightly. A perfectly watertight ceiling should be constructed over the entire switchboard so as to obviate all danger of injury by water falling from overhead.

Switchboard fronts are made of marble and marbleized slate, both of which are suitable for the purpose, when free from seams and metallic veins. Marbleized slate is much superior to the plain stone, as the enamel makes it waterproof. Polished marble is also better than the rough stone, on account of the polish rendering the surface more impervious to moisture. When there is much dampness in the air there is a liability of more or less leakage in the switchboard if the voltage is high. This can be reduced by varnishing the back of the slabs after they have been well dried out by heat.

Fig. 39 shows the back of a switchboard arranged for two generators connected in the three-wire system. The

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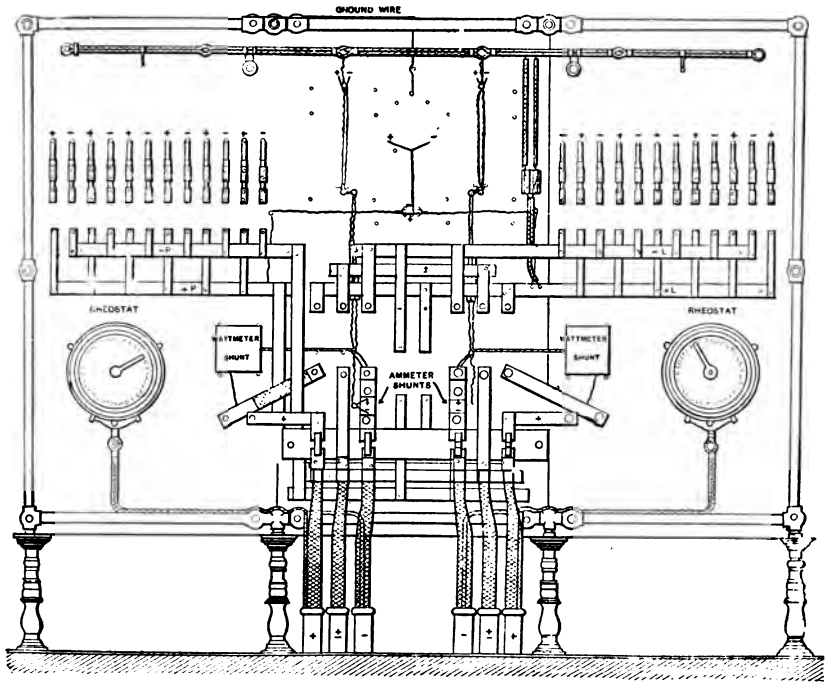

Figure 39. Back of switchboard arranged for two generators and three-wire system.

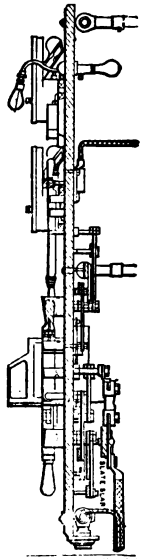

Figure 40.

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leads from the generators come up through the floor and are made of large flexible cables. As will be noticed, all the bars are supported entirely by the connections

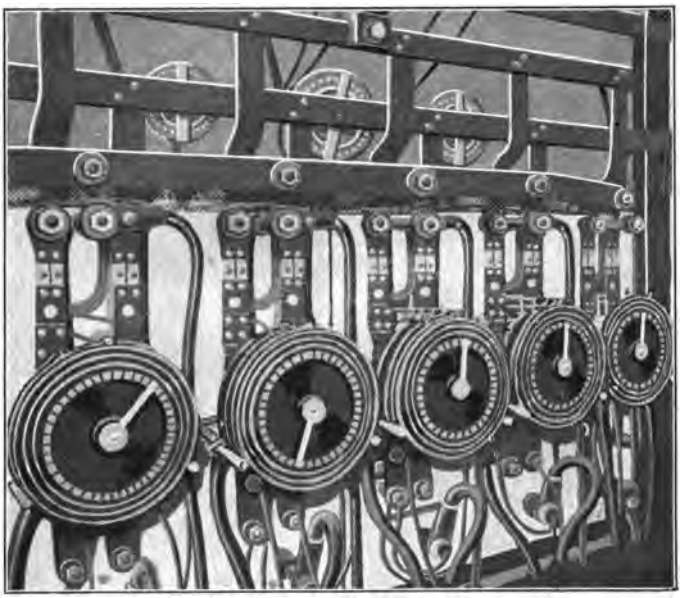

Figure 41
Showing cables and rheostats.

with the switches and other devices, just as in Fig. 27. A side elevation in section is shown in Fig. 40.

Fig. 41 is a photographic view of the back of the switchboard, the front of which is shown in Fig. 42. The five large disks, seen in the back view, are the field rheostats, and by looking at Fig. 42 it will be seen that they correspond in position with the five small hand wheels located in the center panel of the board. This

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As seen from the front.

board, therefore, is arranged for five generators, and the connections are upon the two-wire system, which is shown

Figure 42.

by the fact that the switches in the two side panels are of the two pole type.

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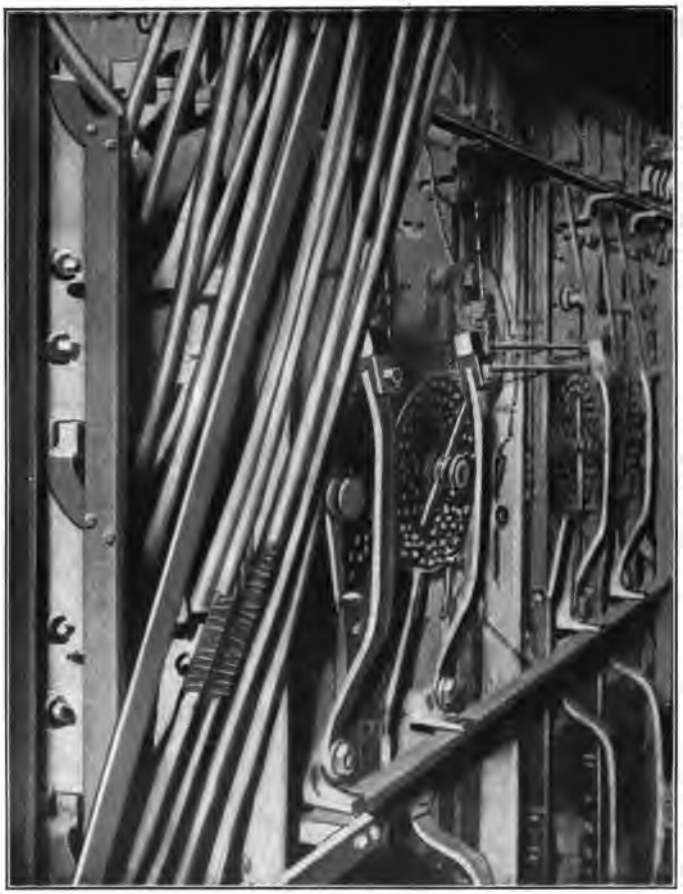

Figure 43
Details of connections at back of figure 44.

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From Fig. 41 it will be seen that in this case, the conductors are in part bars, and in part cables, and they are not secured entirely by the bolts that form the connec-

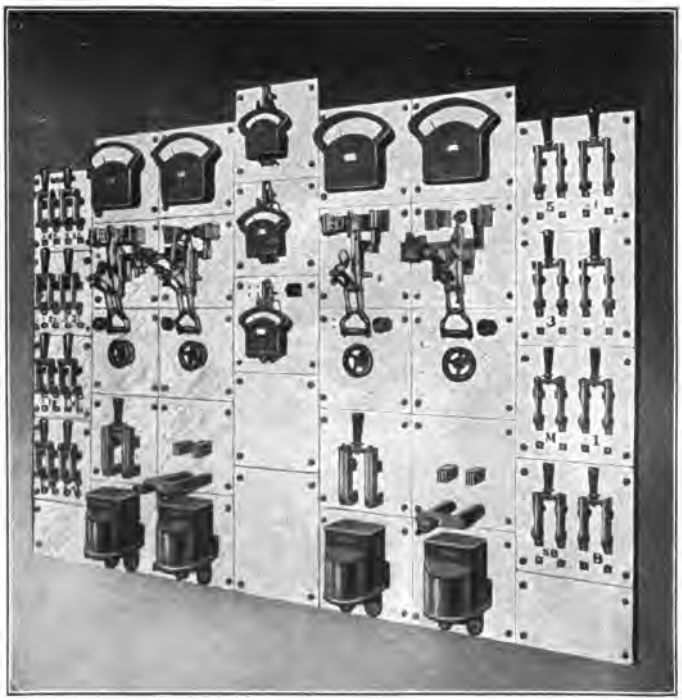

Figure 44
A very complete board.

tions with the switches, circuit breakers, etc., but are also held directly against the marble slabs. This composite construction is commonly followed when the capacity of the plant is small, but when it is sufficiently large, wires and cables cannot be used advantageously, although in

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almost every case the connections with the ammeter, voltmeter, and other instruments are made with cables or

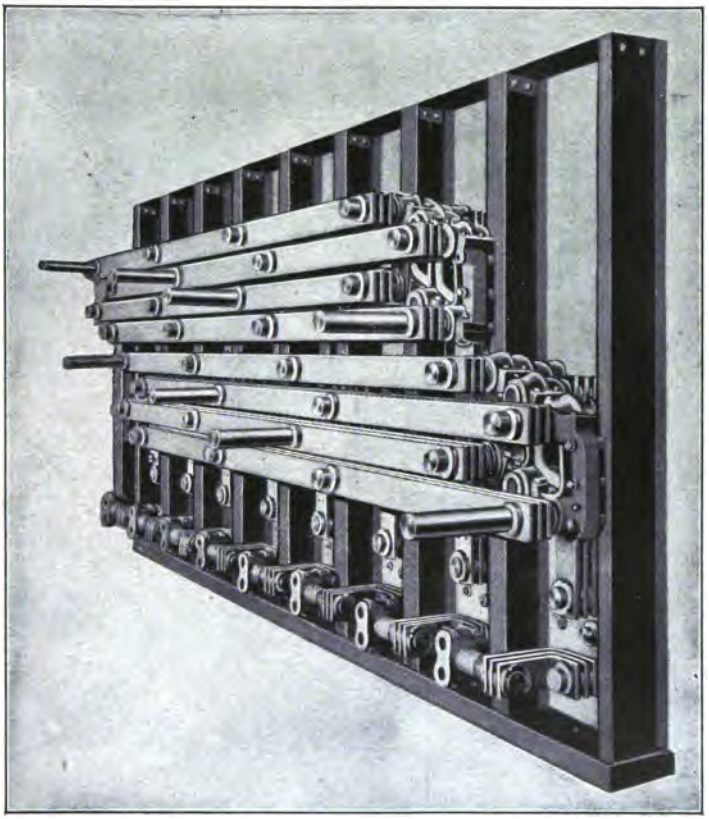

Figure 45
Conductor for heavy current.

wires. It will also be noted, in Fig. 42, that there are five circuit breakers in the middle panel, one for each

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machine, and that in the side panels there are as many circuit breakers as there are switches, showing that each one of the distributing circuits is provided with a circuit breaker.

Figure 46
Another form of heavy conductors.

Fig. 43 shows the back of the switchboard, Fig. 44. In this board, the switches that make the connections with the distributing circuits, are arranged in vertical rows at the side, and as will be seen in the back view, Fig. 43, the circuit wires are run directly from the switch terminals, and are led off at an angle so as to clear each other. The connections from the generators come up through the floor. It will be noticed, in Fig. 44, that

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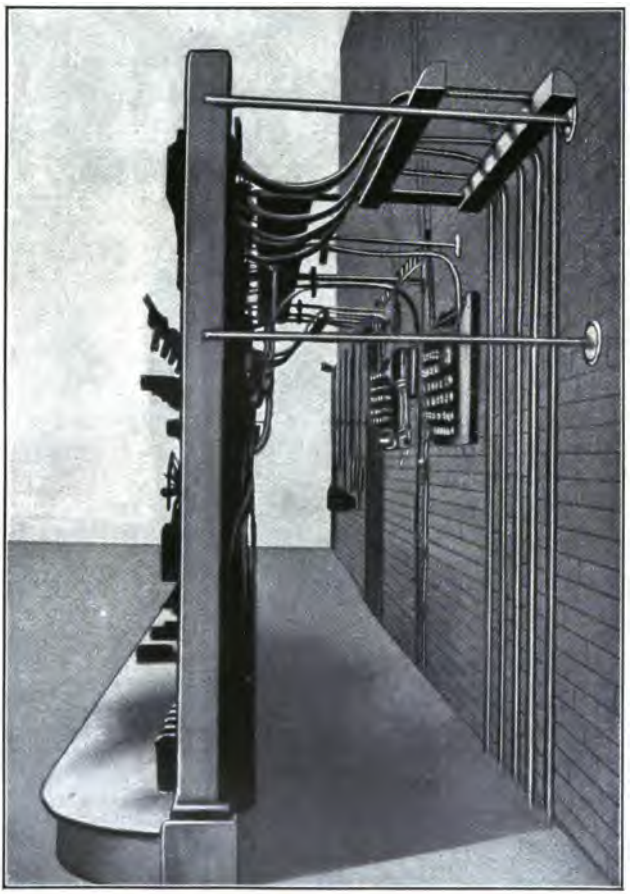

Figure 47
A general view of a small board.

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there are four instruments at the bottom of the board of rectangular outline with cylindrical fronts. These are integrating wattmeters, and are for the electric system what gas meters are for gas systems, that is, they measure the amount of electrical energy that passes through them. One of these meters is connected in the circuit of each generator, and thus the output of each machine can be

Figure 48
Back of three panel board.

read and compared, and by adding the readings of the four instruments the total output of the plant can be ascertained.

When the capacity of a system is large and the e. m. f. rather low, or even if the capacity is moderate, if the e. m. f. is very low, the strength of the current becomes so great, that it taxes the ingenuity of the designer to

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provide room enough at the back of the board for the conductor bars without making the dimensions of the board much larger than they need be for the accommodation of the switches and other devices. As an illustration of such cases is shown Fig. 45, which is the back of a board used in a manufacturing establishment where the e. m. f. is very low, and the current strength runs

Figure 49
Front of figure 48.

up into several thousand amperes. As will be seen, all the connections are of a massive kind, and there is very little waste room between the conducting bars. Another example of a somewhat different design is shown in Fig. 46.

It has already been stated that the switchboard should be set far enough from the wall to allow free access to

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the various parts of the back, and it may be added that the connections should be kept as close to the board as possible. A good example of a snugly arranged board is shown in Fig. 47, which is an end view and shows well the clear space back of the board, and also the way in which the wiring is arranged so as to not encroach upon the space.

Switchboards are often made in a number of panels so that they may be increased in capacity at any time without destroying their symmetry or crowding any of the parts together. A three-panel board of this type is shown in Figs. 48 and 49, the first showing the front and the second the back. The panels *a* and *b* are generator panels and are provided with a main switch, a field regulator, a circuit breaker, and an ammeter. The third panel *c,* is a distributing panel, and is provided with two circuit breakers, two single pole switches, one ammeter and one voltmeter. On the back of the board are also provided lightning arresters for all the conductors. This board is arranged for operating an electric railway, and it only requires one distributing panel, because the road is small. It will be noticed that this board is made up of panels that are duplicates of each other, so that if at any time it becomes necessary to enlarge the plant, the switchboard can also be enlarged by the addition of more panels.

▼ ▼ ▼

Switchboards for arc-lighting circuits.

The construction of arc light switchboards is very simple in comparison with constant potential boards. This difference arises from the fact that each machine

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is arranged so as to feed into a single circuit, and also because circuit breakers and voltmeters are not required. A simple arc light board for four generators is shown in Fig. 50. It consists of a marble slab which carries eight plug receptacles at the upper edge, and eight more at the bottom, and an ammeter in the central space. Eight wires

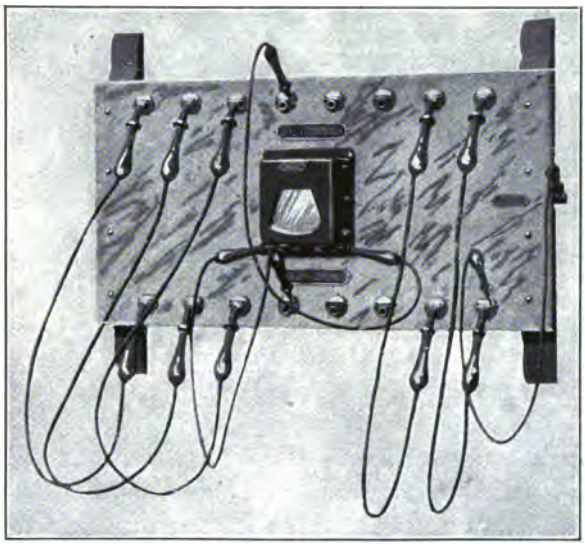

Figure 50
Simple arc light switchboard.

running from the terminals of four machines are connected with the eight lower receptacles, and eight line wires are connected with the eight upper receptacles. By means of the flexible cables shown, any one of the lower receptacles can be connected with any one of the upper ones, as is clearly indicated in the illustration. A

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voltmeter is not required, owing to the fact that the e. m. f. of the generator is continually rising and falling in accordance with the demands of the circuit. If the num-

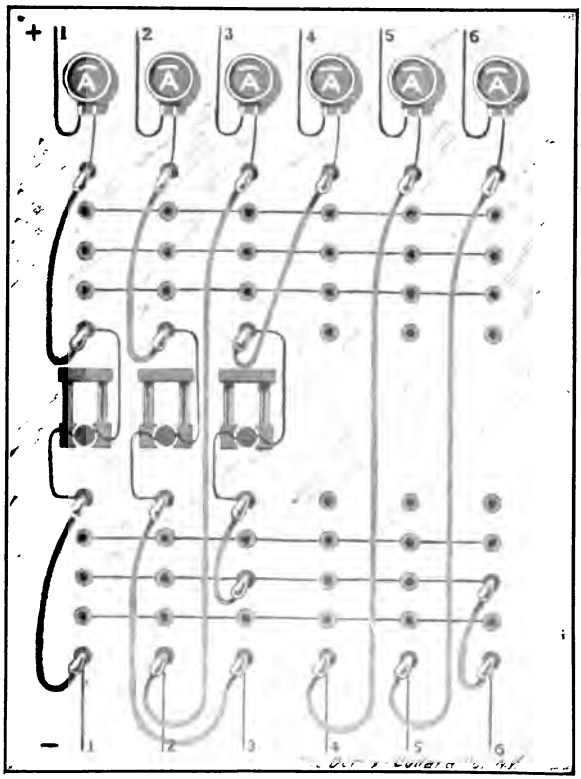

Figure 51
Diagram of arc light board.

ber of lamps in service is increased, the e. m. f. must correspondingly increase, and if the number of lamps is re-

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duced, the voltage must also reduce. This variation in the e. m. f. is effected by the regulator of the machine. An ammeter is required, however, because the current must remain constant to keep the lights from varying in brilliancy. In the board shown in Fig. 50 there is only one ammeter; therefore, this can only be used from time to time to test the several circuits and ascertain whether the current strength is what it should be or not. In more complete and expensive boards, one ammeter is provided for each circuit, and this is left in service all the time so that the strength of the current may be observed without going to the trouble of cutting the instrument into the circuit.

The switchboard connections of an arc light system are clearly shown in Fig. 51, which is so simple a diagram that an extended explanation is not necessary. It will be noticed, however, that the number of receptacles or sockets is greater than in Fig. 50, there being five rows at the top and five at the bottom. The advantage of this arrangement is that by means of two short cables a machine whose terminals run to one end of the board can be connected with a circuit whose terminals are connected with the other end, and thus the confusion arising from the use of long cables is avoided. If there are only a few machines, this construction is of no particular advantage, but in cases where a large number of circuits are to be provided for it is.

In Fig. 51 the first machine is arranged to feed into one circuit only, the second machine supplies two circuits that are connected in series, and the third machine supplies three circuits connected in series. This way of connecting the circuits is not often used at the present

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time, but was quite common in former days when small size generators, ranging from sixteen to twenty-five lights, were to be found in most arc-lighting stations. With such machines there is no special objection to connecting a number in series as their combined e. m. f. is not more than that of one large generator. The connection of the circuits in series in the diagram serves to illustrate clearly the advantage of providing a number of sockets connected with each other in the manner indicated by the horizontal lines. As will be noticed, the second and third circuits are connected in series with each other, and with machine No. 2 without the aid of the horizontally connected sockets; but the last three circuits and the third machine are connected in series through the lower middle row of sockets by the use of two short cables, one running from the lower No. 6 terminal, and the other from the left side of the generator. The second machine could also be connected in this manner, as lower terminal No. 3 could be connected with the lower row of sockets, and the generator could be connected with the top row. In this particular case such an arrangement would be of no special advantage, as the cable from the lower machine terminal to lower 3 is not long and does not cross any of the other cables. In the case of the third machine, however, if a cable were run directly from lower 6 to the machine terminal, two cables would be crossed. As can be seen from this explanation, if the board were made of sufficient size to accommodate twenty or more generators, with an equal number, or more of circuits, the complication arising from direct cable connection from the machine to the circuit terminals would be very great. All this complication could be avoided if

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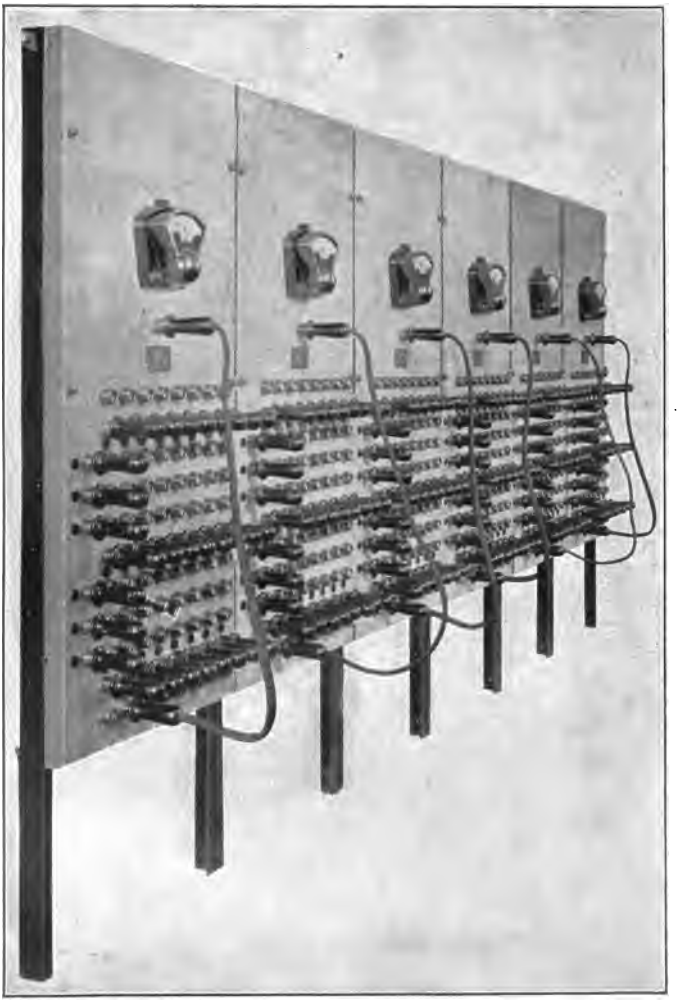

Figure 52
General Electric Co. arc light board.

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each generator were connected with the same circuit at all times, but such is not the case in practice; for one reason or another the machines are frequently shifted from one circuit to another, so that machine No. 1 may be connected with circuit No. 1 one day and with circuit

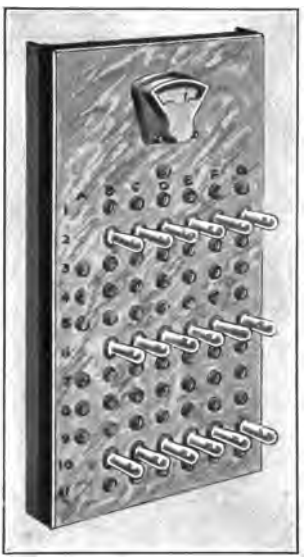

Figure 53
For three circuits.

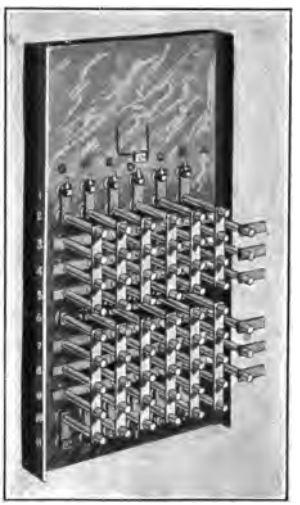

Figure 54
Back of figure 53.

No. 20 the next day; hence, an arc light switchboard should be so arranged that any machine may be connected with any circuit, with the least amount of trouble and the least liability to create confusion in the connections, or to produce grounds, short circuits or cross connections.

The sockets on switchboards of the type illustrated in

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Figs. 50 and 51, are made in various forms, and this is also true of the plugs that form the terminals of the connecting cables. In every case, however, the parts are arranged so that when brought together a good and

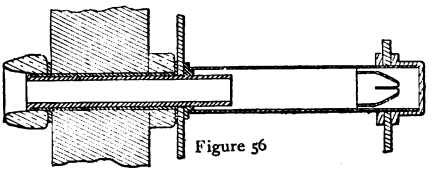

Figure 56

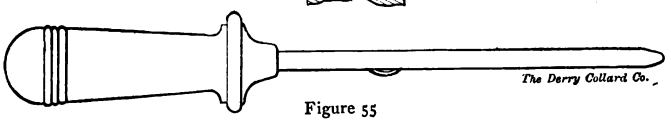

Figure 55

permanent electrical connection is made, and some kind of catch or retaining device is attached to either the plug or the socket to hold the two together firmly, which can be easily disengaged when it is desired to remove the plug, by simply turning the latter around its axis, by lifting or depressing or by giving it a side movement.

By an elaboration of the principle of construction employed in Fig. 51 a switchboard can be made so that all possible combinations of machine and circuit connections can be effected without the use of cables. As can be readily understood, such a modification will greatly simplify boards arranged to control a large number of circuits, and it is the construction that is used at the present time in almost every case.

From an examination of Fig. 51 it can be seen that if vertical bars are placed a few inches back of the horizontal bars in line with the vertical rows of sockets, any one of the bars of one set can be connected with any one of the bars of the other set by inserting in the proper

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socket a connecting plug long enough to reach through to the vertical bars, and provided with arrangements to make contact with both sets of bars. This is the construction used in switchboards in which cables are dispensed with. Fig. 52 shows a board of this type. In the details of construction, however, a considerable difference can be found between boards made by the various manufacturers. The switchboard, Fig. 52, is the type made by the General Electric Company, and the actual construction can be made clear by the aid of the line drawings, Figs. 53 and 54, which show the front and back of a single panel arranged for three circuits and three machines. The machines are connected with one end of the vertical bars, and the lamp circuits with the other ends. It makes no difference which end the machines are connected with, whether the top or the bottom. With plugs inserted in the socket as shown in Fig. 53, the vertical bars are connected from top to bottom, so that top *A* is connected with bottom *A*, top *B* with bottom *B*, and so on for the other bars. If the plugs in the row 10 are taken out the three circuits will be opened, each one at two points, as can be clearly seen from Fig. 54, if it is understood that the tubes connecting the vertical and horizontal bars are made of insulating material. The circuits will also be opened if the plugs in row 2 or row 6 are removed. When all the plugs are removed, each side of each circuit is opened at three points. Owing to the fact that the vertical bars are disconnected at lines 2, 6 and 10, it is possible to connect the lower end of one pair of bars with the upper end of another pair by simply inserting plugs in the proper sockets on lines 3, 4, 5, 7, 8, 9. To illustrate the

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matter more fully, suppose it is desired to connect machine No. 1 with circuit No. 1, then the plugs B_2 C_2, B_6 C_6, B_{10} C_{10} must be inserted; but if it is desired to run machine No. 1 on circuit No. 2, then plugs B_2 C_2 are not inserted. In their stead plugs B_5 D_5 and D_2 are inserted to connect machine terminal B with circuit terminal D, and plugs C_4, E_4, E_2 are inserted to connect machine terminal C with circuit terminal E. In making this connection we have used the horizontal bars 4 and 5; the remaining four bars, 3, 7, 8, 9 can be used in like manner to make any desired combination of the other two machines and circuits.

The row of A sockets is for the purpose of connecting the horizontal bars of one panel with those of the adjoining panel. The sockets C, E, G on line 11 are constructed so that a twin cable with split plug may be inserted for the purpose of cutting the ammeter into the circuit.

The construction of the plugs can be understood from Fig. 55 and that of the sockets from Fig. 56. The tube which forms the body of the socket, and the support for the vertical bars, is made of hard fiber, and is provided with a metallic tube lining at the entering end, and a split metallic sleeve at the other end. The metallic lining is connected with the horizontal bar and the split sleeve with the vertical bar. When the plug is inserted its point is forced into the split sleeve, and a spring projecting from the side like the spring of an umbrella forces the back end against the side of the metallic lining and also acts to hold the plug in place. The plug being a metal rod, its insertion in the socket closes the circuit between the tube lining at one end and the split sleeve at the other.

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Switchboards for alternating currents.

The construction of alternating current switchboards is substantially the same as that of continuous current boards; whatever difference there may be between them is in the way of increased strength of insulation. Where currents of very high voltage are handled the switches are generally placed at a considerable elevation above the floor and are separated from each other by means of marble slabs, so as to prevent arcing from one to the other. The construction of the switches is also considerably modified, and for strong currents they are frequently made so as to be operated by electromagnets or compressed air. Switches of this kind are also made so as to be immersed in oil for the purpose of reducing the size of the sparks when the switch contacts are separated.

All the apparatus and instruments used on continuous current switchboards are used on alternating current boards, and, in addition, several other devices that are not required on the former. The object of these devices, and their location in the circuit, can be made clear by the aid of simplified diagrams.

Fig. 57 shows the switchboard instruments and apparatus, and the manner in which they are connected in the circuit for controlling one single phase alternating current generator. The generator is shown at *A*. The field magnetizing coils are energized by a continuous current derived from a small continuous current generator shown at *E*. The current from the alternator reaches the switchboard through the main switch *D*, and the right-side

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wire runs to and through an ammeter *Am*, and through a fuse *C* to the terminal *L'*. The other side of the circuit runs directly to fuse *C* and thence to terminal *L*. At *H*

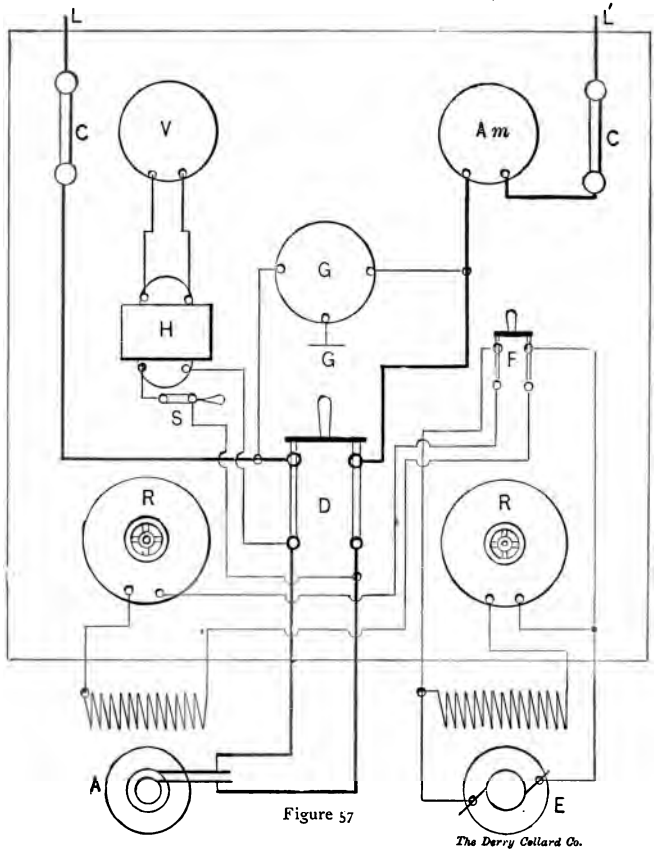

Figure 57

The Derry Collard Co.

Switchboard for single phase alternating current.

is shown a voltmeter transformer, the primary of which is connected across the circuit between switch *D* and the

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alternator. If the voltage of the alternator is low this transformer is not required, and the voltmeter is connected directly across the line, just as in a continuous current system. For high voltages a transformer is used so as to obtain a current of low e. m. f. to actuate the voltmeter. It is not advisable to make voltmeters for very high e. m. fs. on account of the very small size wire required for the coils. If the current delivered by the alternator is large, a transformer may be provided to furnish a secondary current to actuate the ammeter. If a transformer is provided for this purpose, its primary coil is connected in series with the main circuit, and not across it, as is the case with the voltmeter transformer *H*. The latter is connected across the line so that the current traversing its primary coil may vary with the e. m. f. of the alternator; but as the ammeter is to indicate changes in the strength of the alternator current, its primary must be connected in series with the main line. The voltage of the current furnished by the exciter *E* is regulated by means of a rheostat *R'* which, as will be seen, is connected in the field circuit of this machine. Another rheostat *R* is provided in the main circuit of *E*, by means of which the field exciting current of *A* can be adjusted. By means of the switch *F* the circuit through the field coils of *A* can be opened or closed. As can be seen, the strength of the field magnetizing current of *A* can be regulated by both the rheostats, as *R* varies the current by changing the resistance in the circuit, and *R'* varies it by changing the voltage. When economy is practiced one of the rheostats can be dispensed with, generally *R'*. The fuses *C C* can be replaced by circuit breakers, or both devices can be used. The main switch *D* can be a

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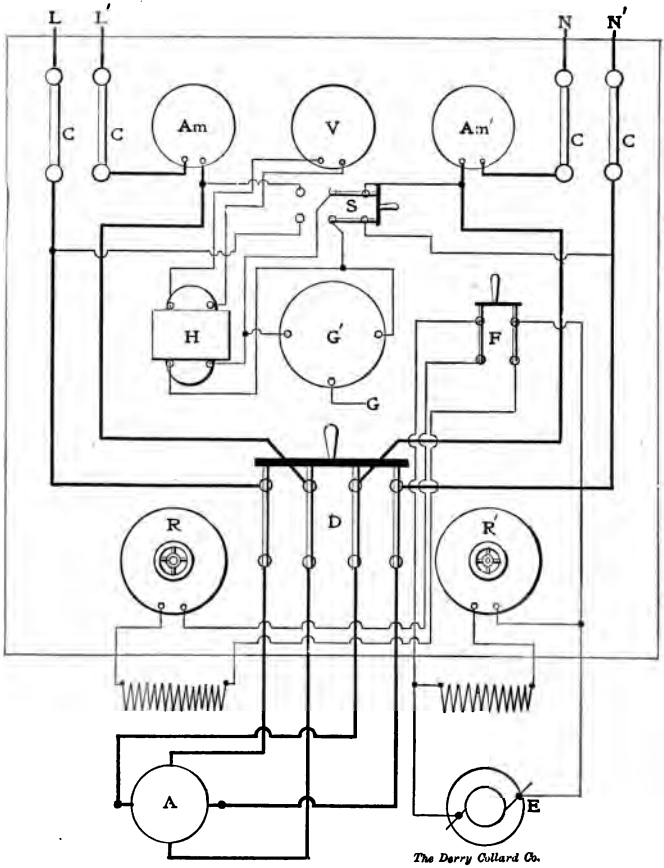

Figure 58
Switchboard for two phase generator.

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simple switch or a combined switch and circuit breaker. If it is the latter, *C C* will be fuses, or they may be dispensed with in a cheap construction. At *G'* a ground detector is placed and is connected with both sides of the circuit as shown, and also with the ground as indicated at *G*.

Fig. 58 shows a switchboard for one two-phase generator. As in the last diagram, *A* is the generator, *E* the exciter, *R R'* the regulating rheostats, and *D* the main switch. The current taken from the side terminals of *A* passes to the two blades of *D* on the right side, and thence to the line terminals *N N'*, one side of the circuit passing through the ammeter *Am'*. The top and bottom terminals of the generator are connected with the two left-side blades of *D*, and this circuit runs to the terminals *L L'*, one side passing through ammeter *Am*. As will be noticed, two ammeters are provided, one for each circuit, but there is only one voltmeter *V*, and this is arranged so as to be connected with either circuit by means of the double throw switch *S*, which connects the primary of *H* with either one of the circuits, according to the side with which it is closed. The operation of the exciter, and the rheostats *R R'* is the same as in Fig. 57. The ground detector *G'* is connected with the center contacts of switch *S* so that by turning this switch in both directions the two circuits can be connected with the ground detector, one at a time. When it is desired to have the two circuits permanently connected with ground detectors, two of these instruments are used, each one being connected with one of the circuits in the manner shown in Fig. 57.

Fig. 59 shows the switchboard connections for one

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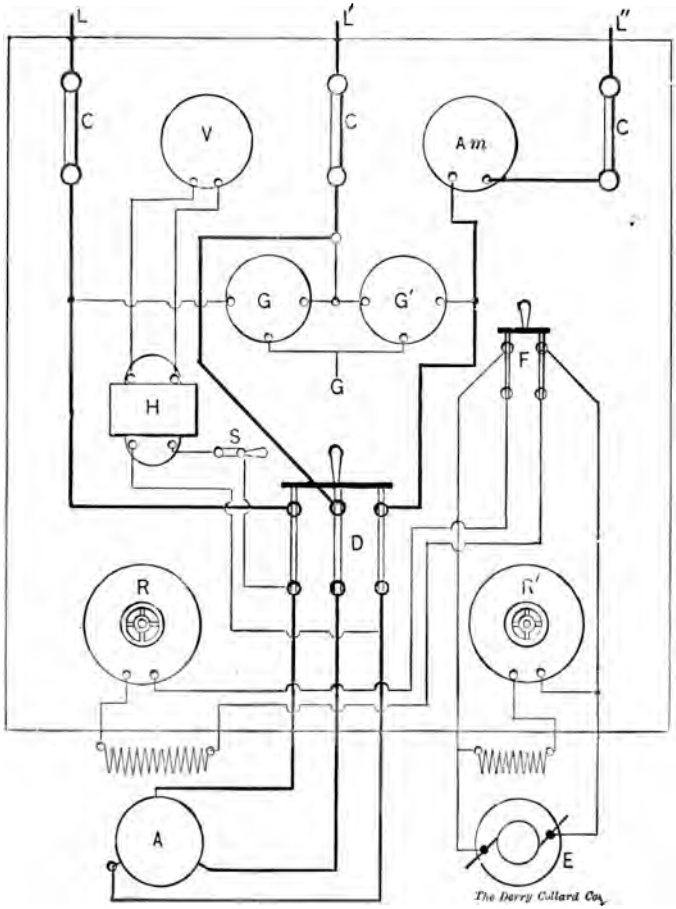

Figure 59

Switchboard for three phase generator.

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three-phase generator. As in the two preceding diagrams, *A* is the generator, *E* the exciter, *D* the main switch, *R R'* the regulating rheostats, *H* a voltmeter transformer, *Am* the ammeter, *V* the voltmeter, *G' G'* ground detectors, and *C C C* fuses in the main lines. It will be noticed here that there is only one ammeter, and this is permanently connected in one of the main lines. The voltmeter is also permanently connected with two of the main lines. In a three-phase system this arrangement is possible, because the currents flowing in the three lines are of the same strength, and the voltage between the lines is the same, hence, with two instruments connected as shown, the condition of the current and e. m. f. in the three lines is properly indicated.

These three diagrams show the switchboards arranged so as to deliver the current into a single set of distribution wires, through which it is conveyed to the point where it is utilized. If it is desired to transmit the current through a number of branches, a panel must be added at one side of the board to hold the switches by means of which these branches are connected and disconnected from the circuit. In this case, the terminal wires *L L' N N'* must be connected with bus bars placed back of the added panel, this part of the board being constructed in precisely the same manner as for a continuous current system. If there are a large number of branch circuits, it will make the switchboard more symmetrical in appearance to place a distributing panel on each side.

When alternating current generators are run connected in parallel, it is necessary to provide apparatus by means of which we can know when the machines are running in

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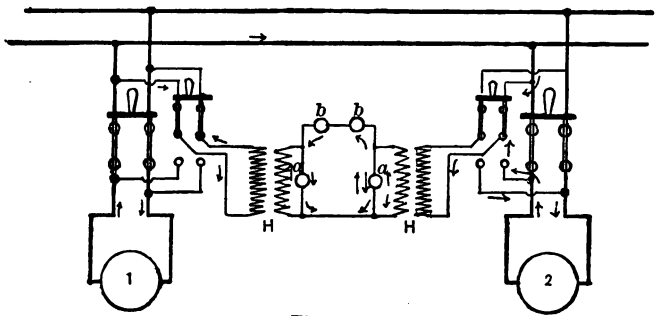

Figure 60 The Derry Collard Co.
Single phase synchronizer.

proper relation to each other to be connected. With continuous current generators all we have to look after in connecting them in parallel is the voltages of the machines, which must be the same; but with alternating current generators, we must also make sure that they are running at velocities that will make the frequencies the same, and, further, that the currents are in phase with each other; in other words, the machines must be synchronized as to frequency, and the currents must be brought into phase before they can be connected in parallel. The apparatus required to accomplish this, and the way in which it is used, can be clearly explained in connection with the diagrams, Figs. 60 to 62.

Fig. 60 illustrates the synchronizing apparatus for a single phase system. 1 and 2 represent two single phase generators arranged to be connected in parallel with the two bus bars shown. *H* and *H'* are transformers whose primaries are connected with the two machines in the manner shown. If the e. m. f. of the formers are not required, as their only office is to furnish generators is one hundred volts, or thereabout, the trans-

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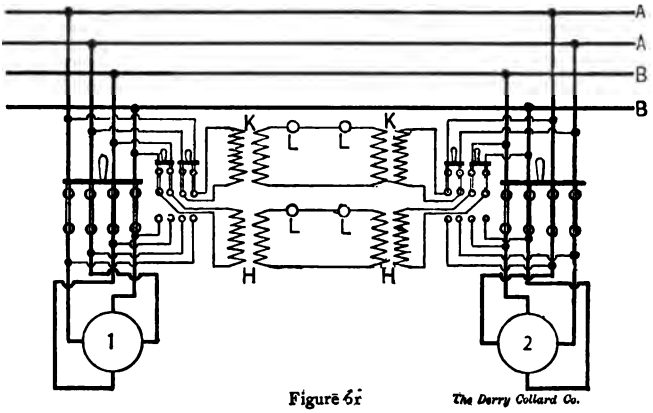
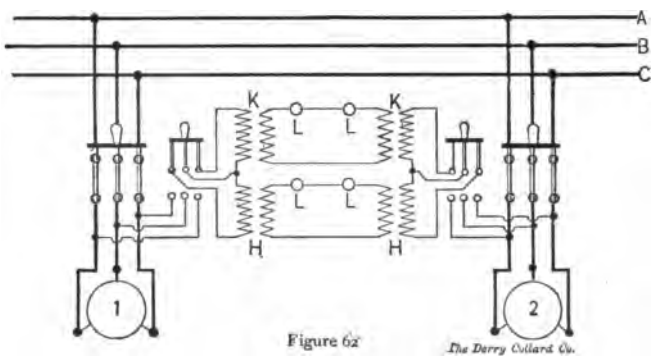


Two phase synchronizing.

secondary currents of low voltage. At *a a* and *b b* incandescent lamps are connected in the circuit of the secondary coils of the transformers in the manner shown. Suppose generator 1 is connected with the bus bars, then the current from it at the instant when it flows upward in the left side line will traverse the primary coil of *H* in the



Three phase synchronizer.

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direction indicated by the arrows, and the current induced in the secondary will flow downward through the left side *a* lamp, causing it to light up. Let the main switch of generator 2 be open and the switch connecting *H'* closed in the direction indicated, then current will pass from the bus bars through the primary coil of *H'* in the direction indicated by the arrows, and this will induce a current in the secondary of *H'* in the direction of the solid arrows, causing the right side *a* lamp to light up. With the current flowing in the two secondary coils in the direction of the solid arrows, there will be no current passing through the *b b* lamps. If, however, the connections of the primary of *H'* are reversed, the current in its secondary will flow in the direction of the dotted arrows and then the lamps *b b* will light up as well as lamps *a a*. Suppose that we now swing over the switch in the circuit of *H'* so as to connect with the generator 2 below the main switch, then if at a given instant the two generators are generating currents that flow in the same direction, the current of generator 2 will flow through *H'* in the same direction it would if it came from generator 1, as is clearly indicated by the arrows; hence, if the connection of the primary coil of *H'* is such that the *b b* lamps will remain dark when both transformers are traversed by current from generator 1, they will remain dark when the current comes from generator 2, providing the two machines are generating currents that are in phase. If the connections of *H'* are reversed, so that *b b* will light up when the current comes from 1, then they will light up if it comes from 2, providing the two machines are in phase. This is what will occur if the two generators are

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running in synchronism. If generator 2 is running faster or slower than 1, the lamps *b b* will light up and go out periodically, as often as the current of 2 comes into phase with 1. If generator 2 is running slower than 1 the lamp *a* on the right will not be as bright as the one on the left. If 2 is running faster than 1 the right side *a* lamp will be brighter than the other. As the velocities of the two generators approach equality, the fluctuations in the *b b* lamps will come at longer intervals, and when both machines reach the same speed the fluctuations will stop and the lamps will remain dark or bright continuously, according to how the primary of *H'* is connected, providing the currents are in phase or nearly so. When this stage is reached, the main switch of 2 can be closed, and thus the generator is connected with the bus bars in parallel with 1. After the two generators are connected the switches of their transformers can be opened, or they can be turned so as to connect with the generators below the main switches.

Fig. 61 shows the synchronizing arrangement for two two-phase generators. As will be noticed, it is simply a duplicate of Fig. 73. The arrangement of lamps, however, is different, the *a a* lamps being omitted. As will be seen, these last-named lamps are not actually necessary, for if generator 1 is running and the switches of *H' K'* are open, the currents passing through the primaries of *H* and *K* will generate currents in the secondaries that will light up the lamps *LL L'L'*, and if the switches of *H' K'* are now closed, the currents generated in the secondaries of these transformers will be either in phase or in opposition with the currents from the secondaries of *H K*, so that they will either help to light

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up the lamps, and make them brighter by doubling the e. m. f. or they will extinguish the lamps by neutralizing the e. m. f.

Fig. 62 shows the synchronizing arrangements for two three-phase generators, and as the principle of action is the same as in the previous diagrams, an extended explanation will not be necessary. In this diagram it will be noticed that the primaries of the transformers can be connected with the generators below the main switches only. It is not necessary to provide a switch that will connect on either side of the main switch, because the upper connections are only required to ascertain the direction in which the transformer primaries are connected, and this has only to be found out when the switchboard is first tried, or when through some circuit changes doubt may arise as to the actual connection. In all such cases, however, if the upper connection with double throw switches are not provided, temporary connections can be made in any convenient manner.

The generators shown in Figs. 57 to 59 are separately excited only, but in almost every case alternators are made so that the field is magnetized in part by a current derived from an independent source and in part by a current derived from the armature, this current being rectified by means of a commutator. The object of this arrangement is to provide means whereby the magnetism of the field may increase as the current increases, so as to maintain the e. m. f. as nearly constant as possible. There are many ways in which the armature and independent currents utilized for magnetizing the field are adjusted, and also in the way in which the armature current is obtained. In some cases it is taken directly from

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the armature through commutators, and in others it is derived from transformers. The latter arrangement is commonly used if the voltage of the generator is high.

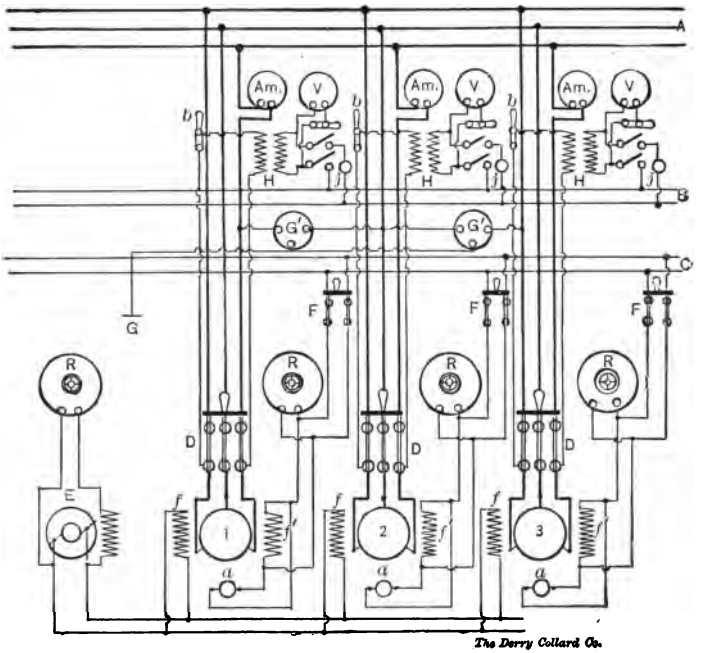

Figure 63
Switchboard for three; three phase generators as used by General Electric Co.

Fig. 63 shows three three-phase generators, provided with field coils f' energized by current derived from the armature, through commutators, and field coils f energized by current obtained from the exciter E. This is an arrangement used by the General Electric Company. It will be noticed that equalizing bus bars are used, and that these

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connect in parallel the field coils f' which are energized by the armature currents. Each generator has an independent regulating rheostat R, which is connected so as to shunt the field coil. The synchronizing transformers are connected with each other through the bus bars B, the main line busses being at A, and the equalizing busses at C. In many cases rheostats are inserted in the circuit of the f field coils so that the current in these coils may be regulated independently. In alternating current generators the coil f acts the same as the shunt coil in continuous current machines, and the f' coil performs the office of the series, or compounding coil.

From the time when alternating currents came into use up to the present day, the lamp synchronizing devices have been used for connecting generators in parallel. While it answers the purpose, it is far from perfect, because the lamps do not indicate closely whether the currents are in phase or not. If the difference in phase is forty or fifty degrees, the lamps will indicate, but small angular differences cannot be detected. When generators are connected in parallel it is necessary that the currents be in phase as well as in synchronism to avoid the passing of strong cross currents between the machines. During the past two years the Westinghouse Company have been manufacturing a synchronizing instrument that indicates correctly the phase of the currents. This instrument, which is called a "Synchroscope," is shown in Fig. 64, and Figs. 65 and 66 show the manner in which it is connected in two and three phase circuits, respectively. The instrument will not indicate with certainty the relation of the currents if the difference in their frequencies is more than about ten per cent., and on that account it is used in

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connection with synchronizing lamps, as shown in the diagrams; the lamps determine roughly the condition of the currents, the instrument being used to make the final adjustment. As shown in Fig. 63 the instrument has two pointers, the vertical one being stationary. The other pointer swings to one side or the other, according to the relative frequencies of the two currents. If the frequency

Figure 64.
Westinghouse synchroscope.

of the incoming machine is greater than that of the bus bars, the movable pointer will rotate to the right, and if it is slower the pointer will rotate to the left. When the two currents are at the same frequency, the movable pointer will stop at some point on the scale dependent upon the phase relation between the currents. When the two currents are in phase, the pointer will stand in the vertical position directly over the stationary pointer.

The ground detectors used with alternating currents are electro-static instruments, except occasionally in cases where low voltages are used. The ground detector made by the Westinghouse Company is shown in Fig. 67, and the way in which the instruments are connected in a three-phase circuit is illustrated in Fig. 68. The tubes placed

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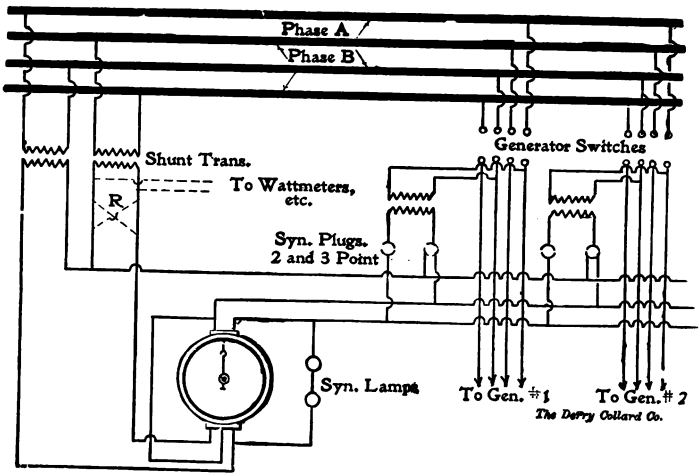

Figure 65
Synchroscope on two phase circuits.

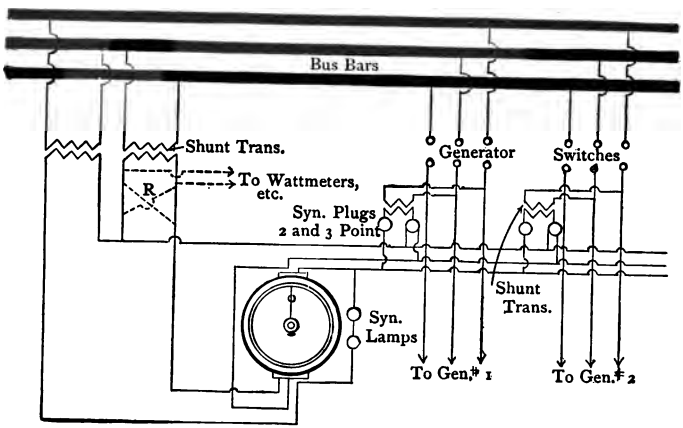

Figure 66
Synchroscope on three phase circuits.

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around the three-line wires are condensers made in cylindrical form. They consist of two metallic tubes separated by a tube of insulating material. The inner tube is connected with the line conductor, and the outer tube with the instrument. It will thus be seen that there

Figure 67
Westinghouse ground detector.

is no direct electric connection between the circuit and the ground.

Some of the manufacturers of alternating current machinery make switchboard panels which are provided with the instruments, switches, etc., required to control the particular portion of the system they are designed for, all properly connected with each other. In building a switchboard to take care of an entire plant, these panels are placed side by side and the corresponding parts of the several panels are connected by means of bus bars. A panel of this kind, made by the General Electric Company to control one single phase generator, is shown in Figs. 69 and 70, the first showing the front and the other the back of the structure. Another generator panel, made

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by the same concern and intended for a three-phase generator, is shown in Figs. 71 and 72. Both of these panels are shown in the manner arranged when intended to control a single generator. When a number of them are placed side by side to control an equal number of

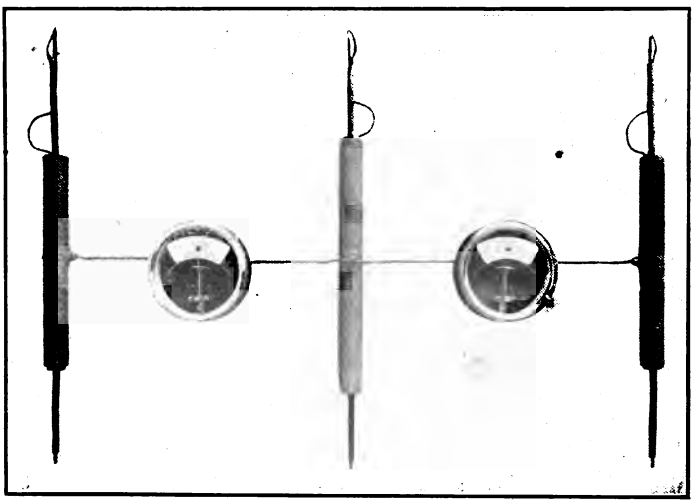

Figure 68
Ground detectors in three phase circuit.

generators connected in parallel, synchronizing lamps and accessories are provided. Fig. 73 illustrates, diagrammatically, the circuit connections of Fig. 69 together with the synchronizing attachments; and Fig. 74, in like manner, illustrates the connections of Fig. 71. All the parts of these diagrams are plainly marked so as to render further explanation unnecessary.

A switchboard made up of panels, manufactured by the Westinghouse Company, is shown in Figs. 75 and 76.

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Figure 69
One panel for single phase generator switchboard.

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Figure 70
Back of figure 69.

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Figure 71
Three phase panel.

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Figure 72
Back of figure 71.

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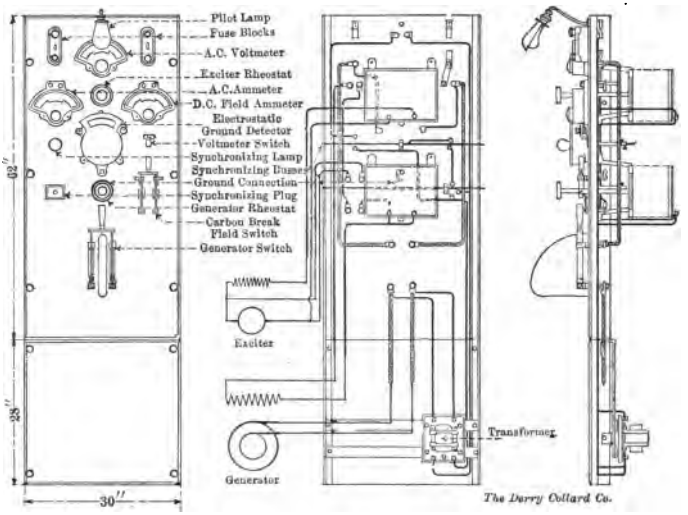

Figure 73
Circuit connections of figure 69.

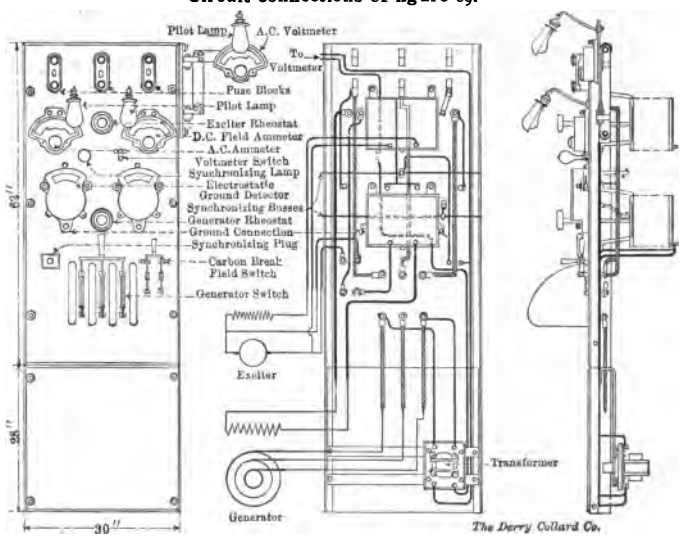

Figure 74
Circuit connections of figure 71.

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A panel Switchboard.

This board consists of two three-phase generator panels and two-line panels, the former occupying the left, and the latter the right side of the structure. Fig. 76 shows clearly the location of the various devices at the back of

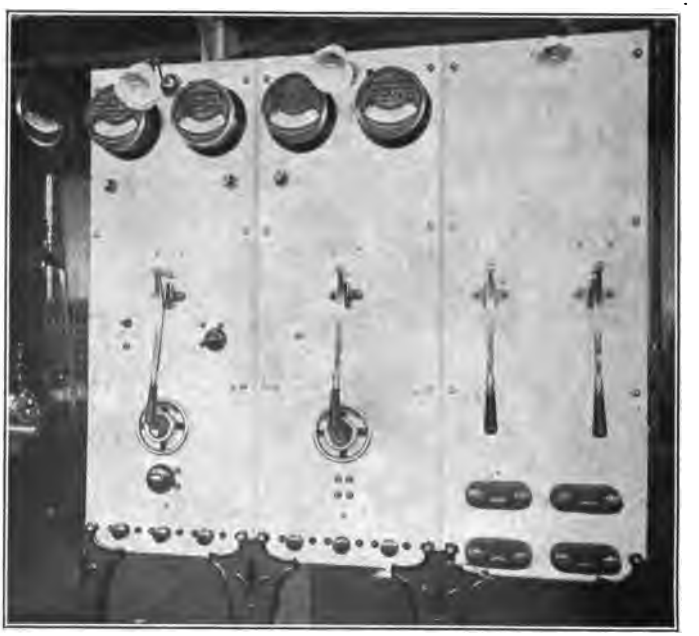

Figure 75
Westinghouse three phase panel switchboard.

the board, including the bus bars for connecting the generators with the line panels. The main switches are arranged so that only the handle is on the front of the board, the other parts being behind it. Each panel is provided with three ammeters, and two voltmeters are mounted upon a swinging bracket at the left. This ar-

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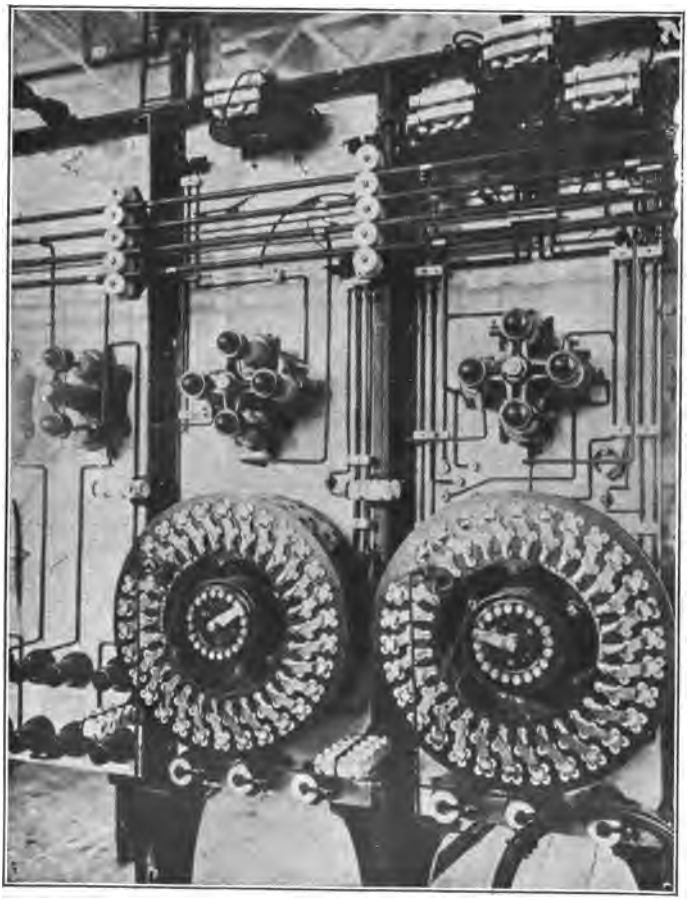

Figure 76
Back of figure 75.

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rangement of voltmeters is quite common, specially with long boards. The line panels are provided with three fuses each, located at the bottom. The sockets seen at the bottom of the generator panels are for the purpose of controlling the exciter circuits. The small sockets, just below the rheostat wheels, are for connecting the voltmeter between any pair of lines. To the right of the first generator panel is seen a ground detector switch by means of which this instrument is connected with the circuits.

▼ ▼ ▼

Switchboards for series alternating current arc lighting.

Arc lights are operated in series by alternating currents derived from transformers provided with mechanical means to maintain the current constant. The switchboards used for this service are constructed upon the same general principle as those used with continuous currents, but, as a rule, each board is arranged to control one circuit only, although there is no difficulty in arranging the lighting and the transformer circuits so that they may be interchanged if desired. The differences between the regular arc switchboards and those used for alternating current service are simply those required on account of the difference in the nature of the currents.

The front and back, respectively, of an alternating current arc switchboard for a 35-light circuit are shown in Figs. 77 and 78. The plugs and sockets are substantially the same as those shown in Figs. 53 and 54. The only devices shown on this board that are not used on continuous current boards are two transformers, one of which

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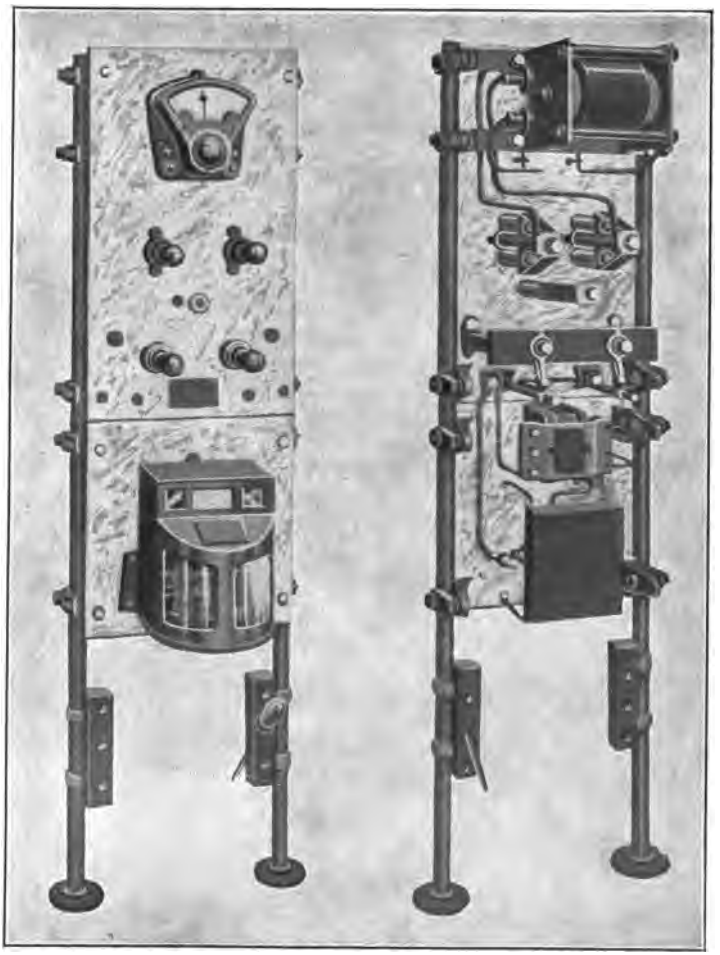

Figures 77–78.
Front and back of alternating current arc light switchboards.

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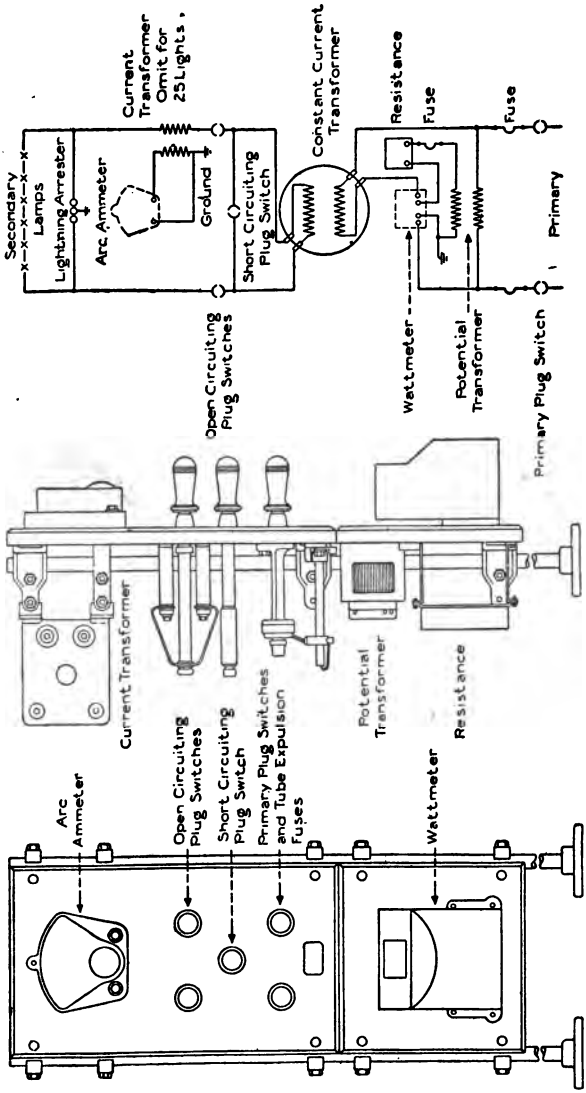

Figures 79-80. Outline diagrams of alternating current arc light boards.
Figure 81. Wiring diagram of same.

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furnishes a current to actuate the ammeter, and the other furnishes one of the currents for the wattmeter. A resistance is also provided with the last-mentioned transformer, to adjust the current it delivers. The ammeter transformer is seen at the top of the board in Fig. 66, and the wattmeter transformer is located directly above the resistance used in connection with it, this resistance being located at the bottom of the board as shown in the figure. The construction of the board, and the arrangement of the circuits and various apparatus can be more fully understood from the explanatory outline drawings, Figs. 79 and 80, and the wiring diagram, Fig. 81. The location of the various devices in Fig. 61 is not the same as in Fig. 79, but as each part is clearly marked, there will be no difficulty in understanding the diagram. As will be seen, the primary current that energizes the transformer, that furnishes the current for the arc lights, runs to the two lower plugs of the switchboard, and the light circuit is connected with the two upper plugs.

The wattmeter shown in these illustrations is an instrument very rarely used in connection with continuous current arc switchboards; this, however, is not because the wattmeter is a necessary adjunct of the alternating current system, but simply because the conditions under which the current is used are such that it is desirable to measure it. In continuous current arc lighting, the switchboard and generators are located in the station, and it would be of no special benefit to provide wattmeters. With alternating series arc lighting, the transformer that furnishes the current, as well as the switchboard, may be located on the premises of the consumer, and in that case it is necessary to have a meter, so as to know what amount of current to charge for.

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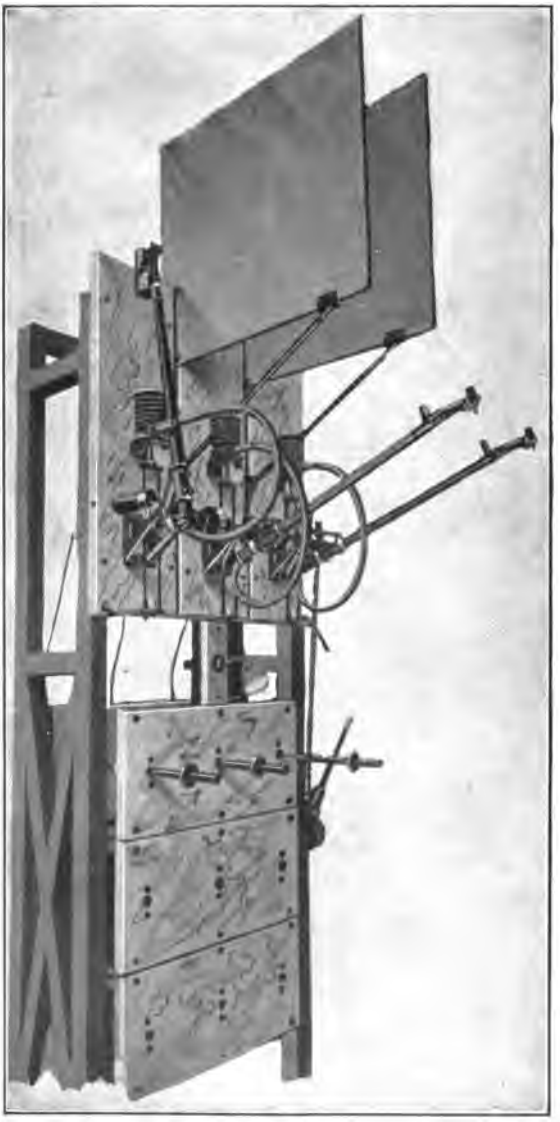

Figure 82
High tension switchboard at receiving station.

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High-tension switchboards.

In power transmission plants, where the energy of waterfalls is transmitted to a long distance, by means of polyphase currents, very high e. m. fs. are used, ranging all the way from 10,000 to 40,000 volts, and the switchboards made for such installations have to be arranged so as to safely withstand such pressure. The switches and circuit breakers used are of special construction so as to produce a long break when they are opened. In addition, these devices are separated from each other by barriers made of suitable insulating material, so that the arc produced on opening the circuit may not jump across from one to the other. The type of switchboards used for such purposes is well illustrated in Figs. 82 and 83, which show the boards at a receiving station at the end of a transmission line. The line current which is impelled by an e. m. f. of 11,000 volts is received in the board, Fig. 82, and from here passes to the primary coils of transformers, which are designed so as to develop secondary currents of 2,200 volts. These secondary currents are conveyed to board, Fig. 83, and from there pass to the distributing circuits, or to other transformers, where they are again reduced and rectified.

The switchboard, Fig. 82, handles the high-tension transmission currents that come from the power station. It consists of three panels, each one made of two marble slabs placed one behind the other. The switching is accomplished by means of plugs and sockets in a manner similar to that employed in the arc light boards already explained. The terminals connected by the plugs are mounted on the marble slabs, the latter being separated

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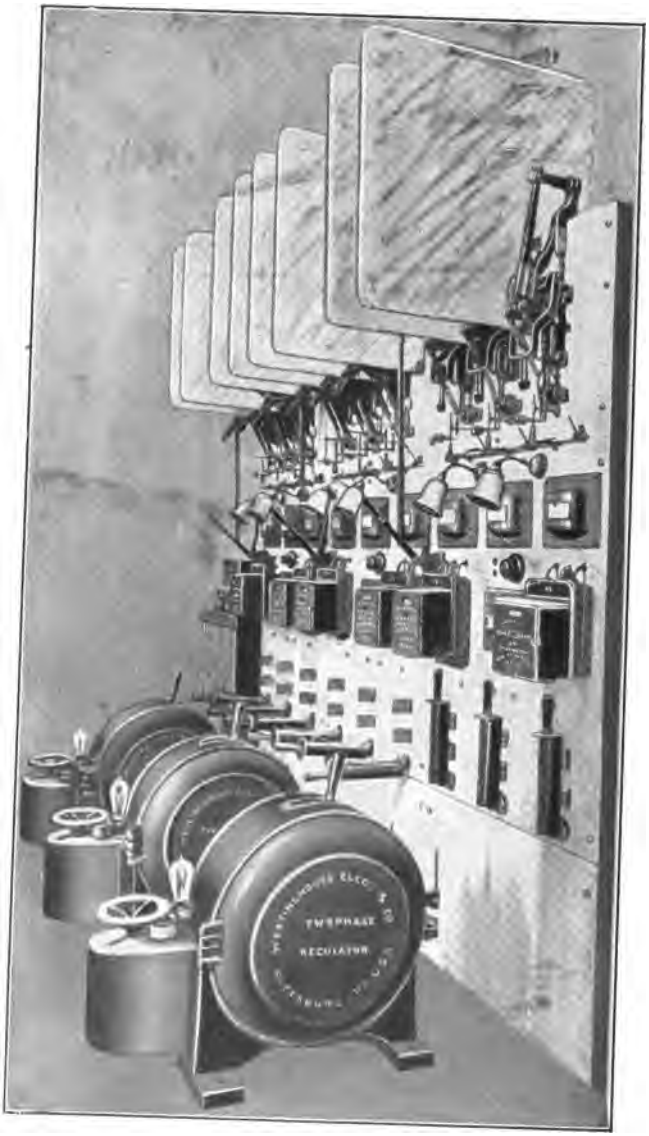

Figure 83
Secondary switchboard, Westinghouse.

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by a space of about two feet. There are two incoming three-phase lines, and three groups of three-phase transformers, and the arrangement of the sockets on the switchboard panels is such that either one of the incoming lines can be connected with any one of the groups of transformers. The incoming lines are provided with circuit breakers that have copper primary, and carbon final breaking contacts, both of which are mounted on the end of vertical arms about five feet long which when released swing out to the horizontal position, making an opening of about six feet. One of these circuit breakers is seen at the top of Fig. 82. The three arms are mounted on a single shaft, being strongly insulated from each other, and are arranged so that they may be operated independently or all together. They are operated by means of elctro-magnets, and the lever and connecting rod on the right are used to close the three arms at once, while the smaller lever higher up is for the purpose of opening them simultaneously.

The board, Fig. 83, handles the secondary current from the three-phase groups of transformers that are connected with the high-tension board, Fig. 82. This board has three panels from which three outgoing currents are controlled. Each panel is provided with circuit breakers similar to the high-tension design but of smaller size, the separation of the contact points being about one foot and a half. In addition to the circuit breakers, each panel contain three ammeters, one voltmeter, arranged to be connected across any of the three phases, two intergrating wattmeters, to measure the power passing to the outgoing circuits, and three main switches, the blades of which are protected by hard rubber shields so that they

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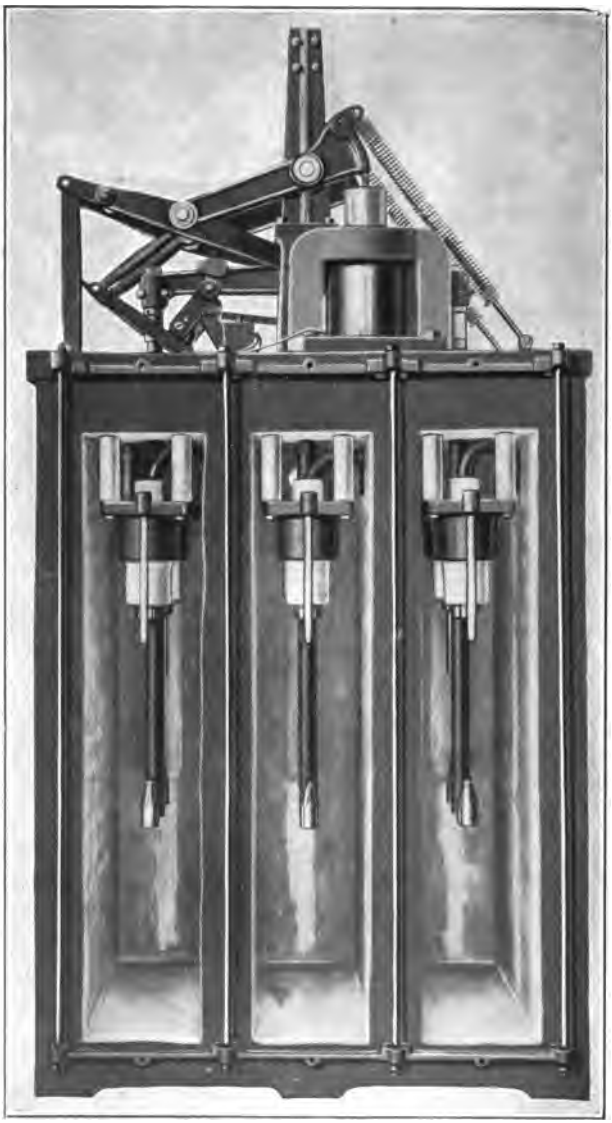

Figure 84
Oil brake circuit breaker for high tension.

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may not be touched accidentally. In both these boards it will be noticed that the circuit breakers are separated from each other by large marble slabs, the object of which is to prevent arcs from striking across from one to another when the circuit is opened.

As is shown in the foregoing, switches constructed to handle currents of high voltage have to be made so as

Figure 85
Westinghouse power factor meter.

to make a long break when they open the circuit. This is the case when they break the circuit in air, but if the contacts are separated under oil, the length of the break can be greatly reduced. Oil break switches are made in numerous designs, some of which are arranged to be operated by hand, and others by means of electro-magnets or pneumatic cylinders. Air-break switches intended for high voltages are also made so as to be operated by electro-magnets or pneumatic cylinders.

An oil break circuit breaker operated by electro-magnets is shown in Fig. 84,

These constructions are used when the switch or circuit breaker is of such proportions that it cannot be readily

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operated by hand. Whether the switch is operated by electro-magnets or compressed air cylinders, a small, manually operated switch is provided to control its movement. If the switch is electro-magnetic, the small operating switch controls the flow of current through its magnets, and thus causes it to open or close at the will of the operator. The pneumatic switches are provided with magnets to open and close the actuating valve, and these magnets are controlled by the small operating switch. The operating switch is generally mounted upon the switchboard, or upon a conveniently located stand, but the main switch itself can be located wherever desired, connecting wires being run from it to the operating switch.

Of late quite a number of devices have been brought out which are for the purpose of rendering the action of some of the apparatus more positive, or to accomplish results that previously existing apparatus did not accomplish. One of the most useful of these devices is an instrument that indicates the power factor of the circuit. This instrument, which is called a "power factor meter," is shown in Fig. 85.

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PART SECOND

SWITCHES

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Switches.

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A switch, properly defined, is any device by means of which a current may be diverted into any circuit, or be cut off therefrom entirely. Switches may be divided according to the manner in which they are moved, and thus we would obtain side-throw switches, plunger switches and vertical throw, or knife blade, switches. A side switch in its simplest form is shown in Figs. 86 and 87, the first being a top view and the second a side elevation.

Switches of this kind are generally arranged to move in one direction only, as is indicated by arrow C, and to prevent movement in other direction the stop post d is provided. This construction is advantageous, as with it in the switch can be closed rapidly without danger of swinging it beyond the closed position. In this position it will be seen that the current will pass from a to b through the switch blades. If the blade is raised in the direction of arrow C the circuit will be opened. When the switch is closed it is necessary that the blade rest firmly upon the stud b, and to render this certain a spring washer is provided at e, Fig. 87, and s is set so that it must spring up slightly to pass b.

Another modification of the simple side-throw switch is shown in Figs. 88 and 89, these being top and side views, respectively. The difference between this and the

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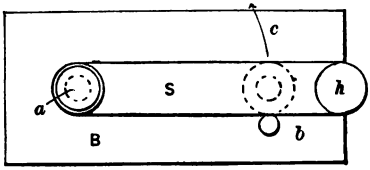

Figure 86.

Figures 86-90 show various types of switches referred to on pp. 145-147.

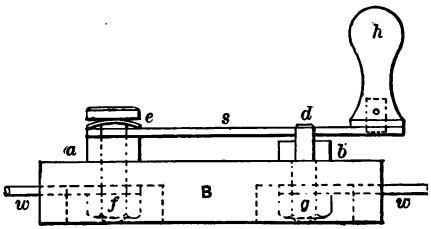

Figure 87.

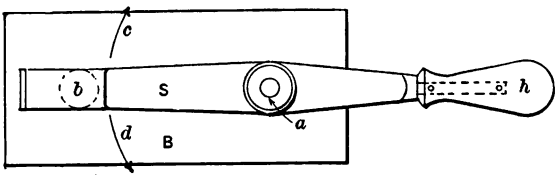

Figure 88.

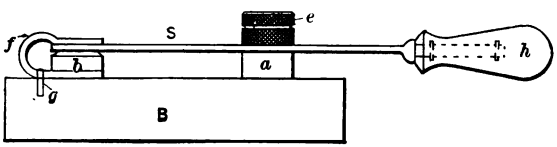

Figure 89.

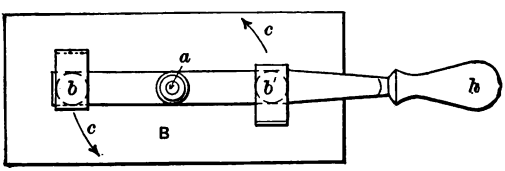

Figure 90.

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former design is that the swiveling point is transferred from the end to the center of the switch blade. With this construction it would be easy for the blade to be raised from b by a downward pressure of the hand of the operator, and to avoid any trouble from such an occurrence the spring f is provided. This spring serves to hold the

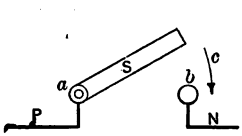

Figure 91.

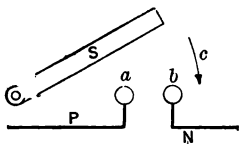

Figure 92.

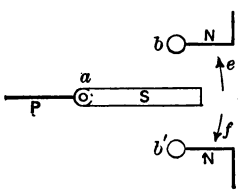

Figure 93.

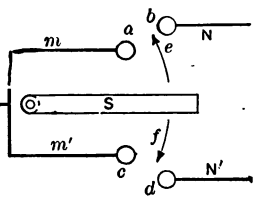

Figure 94.

Figures 91-94—Simple switches.

blade down, as f and b are electrically connected, therefore the current would pass from S to f and thus to b.

In Fig. 90 is shown a switch that can be used for two purposes, one to connect one terminal of a line with two wires, and the other to open or close the circuit at two points at the same time. If the center stud a is connected with one terminal of the line, and b b are connected with separate wires, then it can be readily seen that when the switch blade is moved to the closed position as shown in the figure, the current entering through the wire connected with a will divide and pass out through two wires connected with b and the other with b^1. If one

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end of the line wire is connected with b and the other with b^1, then if the switch blade is moved in the direction of arrows C, there will be a break in the circuit between S

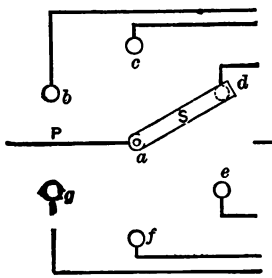

Figure 95-7.

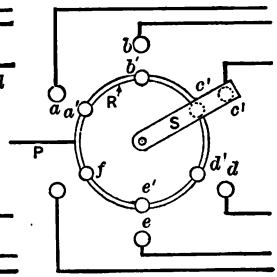

Figure 96.

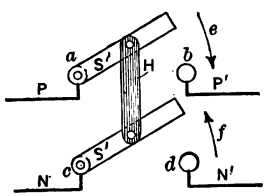

Figure 97.

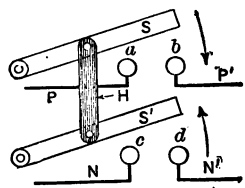

Figure 98.

Figure 95-98. More switch diagrams.

and b and another one between S and b^1, hence the two points in the circuit will be opened at the same time.

Diagram Fig. 91 represents what is called a single-throw, single-break switch.

Diagram Fig. 92 represents a single-throw, double-break switch, and it will be noticed that the difference between it and Fig. 91 is, that S is not pivoted at a, hence when it is in the open position S is entirely disconnected from the circuit. When S is lowered it connects a with b, and when it is raised from this position, two breaks are

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made in the circuit, one between S and a and one between S and b.

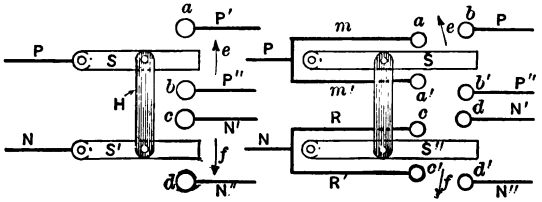

Figure 99. Figure 100.

Figures 99-100. Double throw switch.

Diagram Fig. 93 shows a double-throw, single-break switch and diagram Fig. 94 is a double-throw, double-break switch. In these two figures it will be seen that if S is moved in the direction of arrow e, wire P will be connected with wire N; and if it is moved in the direction of arrow f, P will be connected with N^1; hence there are two directions in which the switch can be moved to close the circuit.

Diagram Fig 95 shows a multi-throw, single-break switch, and diagram Fig. 96 is a multi-throw, double-break switch. In the first figure the wire P can be connected with any one of the six wires leading off from contacts b, c, d, e, f, g, by the movement of S, but in each case the circuit is only opened at one point.

In Fig. 96, however, wire P connects with all the contacts of the inner circle, these being joined by the ring R, and S is not directly connected with P, hence when it is moved so as to connect any two contacts it closes the circuit at two points, just as in the case of Fig. 92.

The switches so far explained are of the single pole type—that is, they open or close the circuit at one place only. The wire P, in these diagrams may be considered as one of the leads coming from the generator.

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Single and double throw switches.

In Fig. 97 to 100 switches of the two pole type are shown.

The switches used on switchboards are almost invariably of the type known as knife switches. They are given this name from the fact that the blade moves in a plane perpendicular to the switchboards surface, like a meat shaver. Switches in which the blade moves in a plane parallel with the surface of the board are occasionally employed, when it is desired to connect one terminal

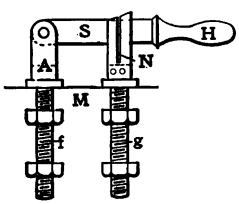

Figure 101.

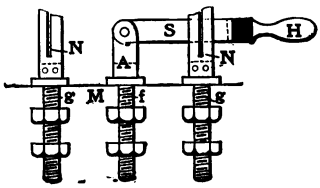

Figure 102.

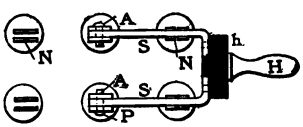

Figure 103.

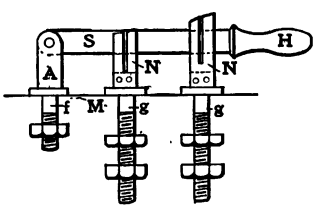

Figure 104.

Figures 101-104. Different types of switches.

with any one of three or more other terminals. Switches of this latter type are designated as side-throw switches. The appearance of a simple knife switch, seen from the side, is shown in Fig. 101, in which S represents the switch blade, A and N the terminals, M the switchboard surface, and f g the studs by means of which the terminals are secured in place and are connected with the conductor bars, back of the board.

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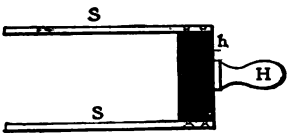


Figure 105.

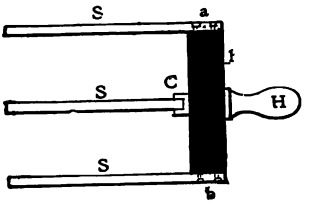
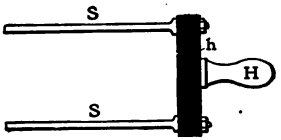


Figure 108.



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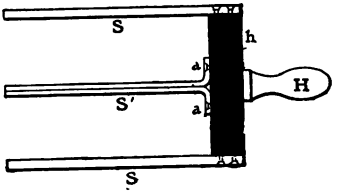

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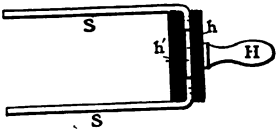

Figure 107.

Figures 105–110. Switch details.

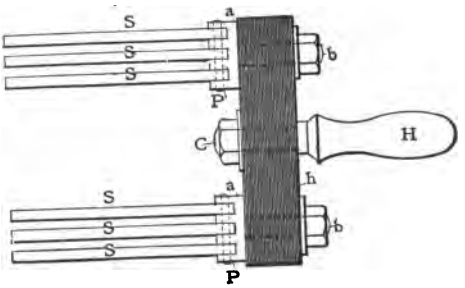

Figure 110.

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Large switches.

The switch Fig. 101 is called a single-throw switch, because the blade can only be thrown in one direction to close the circuit. The design shown in Fig. 102 is called a double throw switch from the fact that the blade will close the circuit if thrown in either direction. If the switch has but one blade it can only open or close the

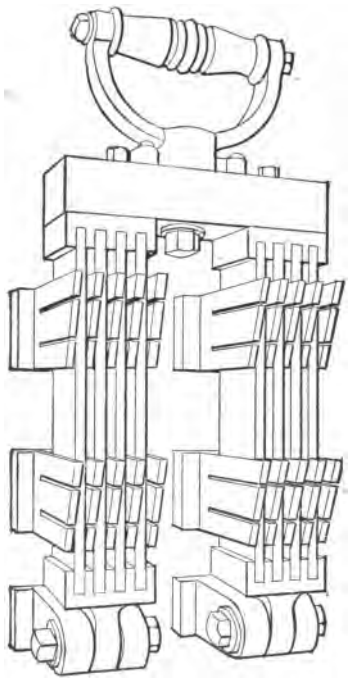

Figure 111. Switch for heavy current.

circuit in one wire, and is, therefore, called a single-pole switch; but if S consists of two blades, as shown in Fig 103, which is a plan of Fig. 102, then if the two blades are insulated from each other, each can open or close the

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circuit through one wire. Switches of this latter type are called double-pole, and if S consists of three insulated blades the switch is three-pole.

In Fig. 102, as well as in Fig. 101, the current passes through A, therefore there must be a perfect fit between A and S. In Fig. 104 the current does not enter through A, hence a loose fit will answer as well as a tight one. In this last figure the current passes through the blade S

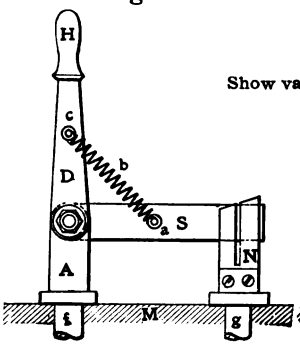

Figure 112.

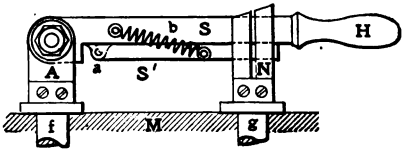

Figure 113.

Figures 112-114
Show various types of quick break switches.

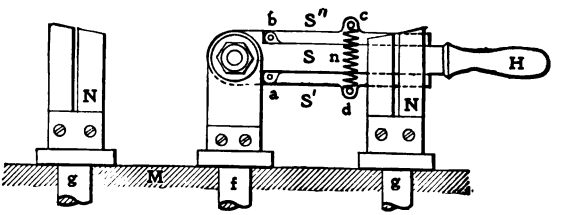

Figure 114.

from N to N; therefore at these points a good fit is required, and N must exert a considerable pressure against S. It can be readily seen that if the blade S is raised in Fig. 104 it will produce two breaks in the circuit. On

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this account switches of this construction are called double-break switches.

If the two sides of S in Fig 103, are not insulated from each other, the switch cannot be used as a double-pole. If the voltage of the current that passes through the two sides of a double-pole switch is low, the insulation need not be very heavy, but for an electro-motive

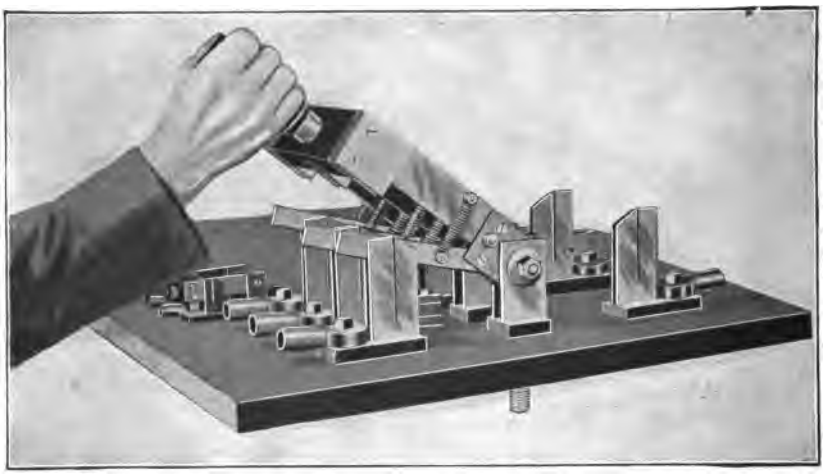

Figure 115. Three-pole, quick-break switch.

force greater than 110 volts the most substantial insulation must be provided. When a two-pole switch is used to connect a generator with the switchboard, the outgoing current passes through one of the blades S and the returning current passes through the other, and since it is much easier for the current to jump across from one side of the switch to the other than to make the journey through a

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weak point in the insulation. To properly insulate the sides of a multiple pole switches several types of construction are resorted to, one of which is shown in Fig.

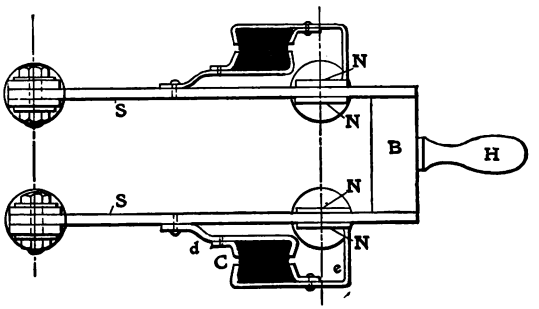

Figure 116.

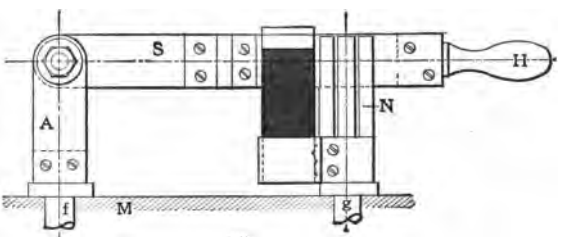

Figure 117.

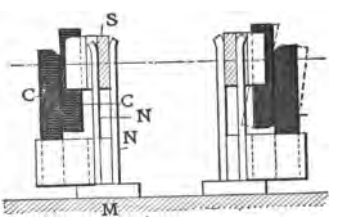

Figure 118.

Figures 116-118.
Switches with carbon contacts.

103. This consists in providing a block, which is made of hard rubber, fiber or hard wood, the former being used for the higher grade of switches and for higher volt-

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ages. The sides S S are bent around at right angles at the ends and are secured to H by means of screws. Other constructions are shown in Figs. 105 to 110.

Figs. 108 and 109 show constructions for three-pole blades, and Fig. 110 is the type employed for switches of large capacity. When a strong current has to be transmitted through a switch, it is not sufficient to make the several parts of sufficient cross-section to carry the current without becoming overheated, but it is also necessary to provide a sufficient amount of contact surface, for if this is not provided the heat developed at the points of contact may be enough to absorb a considerable amount of energy and in extreme cases, may even result in burning out the switch, with more or less serious results. By providing three blades side by side for each pole, as in Fig. 110, the surface of contact is increased three-fold. The actual construction of large switches of this kind can be better understood from Fig. 111, which is a switch made by La Roach & Co., of 3,000 amperes capacity.

When a switch is opened, through which a strong current is passing, a large spark is formed as the switch blades leave the contact, and the effect of this spark is to burn away the metal of both parts. This burning not only results in gradually consuming the working parts of the switch, but by roughening up the surface destroys the perfect contact. The trouble can be remedied by smoothing off the burned portions with a file, but this procedure, in the hands of a man who is not a good mechanic, soon spoils the switch by destroying the fit between the contact surfaces. The extent to which the parts are burned by the spark is dependent not only upon the strength of the current, but also upon the duration of the spark; therefore, if the time during which the

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spark holds out can be reduced, its destructive effects can be reduced. To reduce the duration of the spark switches are made so as to move quickly after they break contact, and the way in which the result is accomplished can be understood from Figs. 112, 113 and 114. Switches of this kind are called quick-break or snap switches.

Fig. 115 shows a three-pole switch of the type shown in Fig. 114, the handle being raised to the point where the side bars are about to leave the contacts N. Quick action switches succeed in reducing the destructive effect of the spark upon the switch, but are not very desirable so far as the generator and motors in the circuit are concerned, owing to the fact that if the duration of the spark is reduced the strain upon the insulation of the generators and motors is increased. When a circuit is opened the current tends to keep on flowing, and as the regular channel is disconnected, it tries to complete a circuit through some other path. If there are weak points in the insulation they will be pierced by the current in its effort to close the circuit. The action of an electric current in this respect can be compared to that of a current of water brought to a sudden stop. Now, in the case of the water current, if the flow is checked instantly the force exerted by the current becomes very great, but if the flow is stopped gradually the reverse is the case. With electric currents the result is exactly the same, if the current passes through wire coils wound upon a mechanism. If the current dies out slowly the kick, as it is commonly called, is slight; but an instantaneous stop may produce an enormous reaction, even if the current is small.

From this it will be seen that quick-action switches are objectionable because they increase the strain brought to bear upon the insulation when the current is inter-

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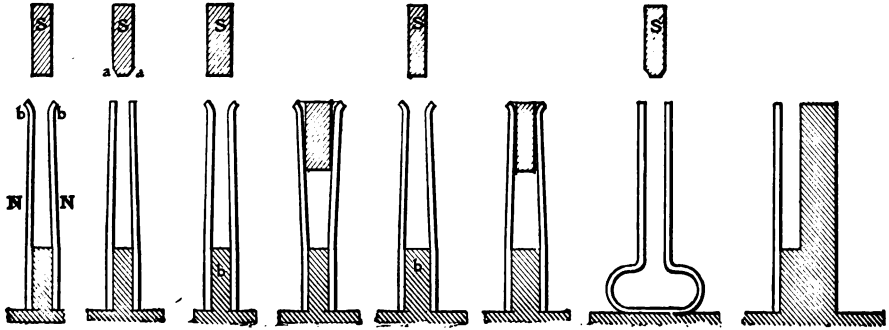

Fig. 119. Fig. 120. Fig. 121. Fig. 122. Fig. 123. Fig. 124. Fig. 125. Fig. 126.

Figures 119-126. Show construction of switch contacts.

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rupted. To obviate the objection of the quick break and at the same time protect the switches from the destructive action of proionged sparks, the type of switch shown in Figs. 116, 117, 118 is used. In this switch two sets of contacts are provided, one being made of copper and the other of carbon blocks. The first set of contacts is for the purpose of conducting the current with the least resistance possible, and the second set is to receive the spark at the instant when the current breaks.

Switches of the type shown in Figs. 116, 117, 118 are made in many designs, but they are not used as extensively as formerly, except in connection with circuit breakers. For although they prevent the destructive action of the sparking upon the switch blades and contacts, they are rather bulky and more liable to get out of order than the plain type.

The stationary contacts N, and the blades S of switches should be made so as to fit well, and also so that when the blade is lowered it will not be caught upon the ends of the jaws. Some manufacturers provide against the latter difficulty by bending the ends of the jaws outwardly, as in Fig. 119, while others leave them straight as in Fig. 120, and bevel corners of the blade. The most important point about the jaws and of switches is to make them so that they will fit well. If the jaws are made long, they may apparently fit well when in reality they do not. To obtain a good fit, the part b to which the jaws are fasened should be of the same width as the blade S. The jaws should be made of sheet copper rolled hard so as to be springy. They should be bent at the upper edge of b, but only enough to slightly reduce the width of the opening at the top ends.

With such construction, if S and b are of the same

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width, the jaws will stand parallel when the blade is in place, and there will be a bearing from edge to edge of S. If S is wider than b, as shown on Fig. 121, the effect will be as shown in Fig. 122 when the blade is in place; and if S is narrower, as shown in Fig. 123, the fit when

Fig. 127.

Fig. 128.

Two Crouse-Hinds switches.

the blade is in place will be as illustrated in Fig. 124. The thickness of the jaws should be sufficient to make them decidedly stiff, so that they may have to inward a very small amount to produce the necessary clamping pressure. Some switch jaws are made of the form illus-

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trated in Fig. 125, this construction being used under the erroneous impression that if there is sufficient elasticity, a bearing can be obtained over the entire width of the switch blade regardless whether the fit is good or bad. This notion is not correct; the best results are obtained with short jaws, but the perfect fit is a matter of accurate workmanship.

As the resistance of the contact surface of the switch jaws is much greater than that of the body of the conductors, an extra amount of heat is developed at these points, and for this reason it is desirable to have as much metal near the contacts as possible. One way of increasing the bulk of metal is shown in Fig. 126. It is very commonly used in switches of the side-throw type, in which case the thick side of the jaw rests upon the surface to which the switch is attached, and the spring is placed on top. Some of the commercial forms of knife switches are shown in Figs. 126 to 129.

For the high voltages used in alternating current circuits, it is necessary to devise means whereby the sparking produced when the switch is opened may be reduced to small magnitude, if this construction is not employed, then the contacts must be of such form that they will withstand heavy sparking without being seriously injured. To prevent the sparks from attaining a destructive magnitude, several expedients are resorted to, one of which is to place the contact point in a tank of oil. When switch is so arranged, the spark at the instant of opening the circuit is very small because the oil is a very high insulator, and being liquid, it immediately falls into the space left by the switch contacts, and thus, by interposing an insulator or very high resistance in the break between the contact points, the flow of the current is at

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once stopped. Even with an e. m. f. of two or three thousand volts, the spark produced when the contacts are separated under oil are very short, probably not more than a sixteenth of an inch. Such small sparks are necessarily of short duration, so that the burning effect upon the switch terminals is very slight.

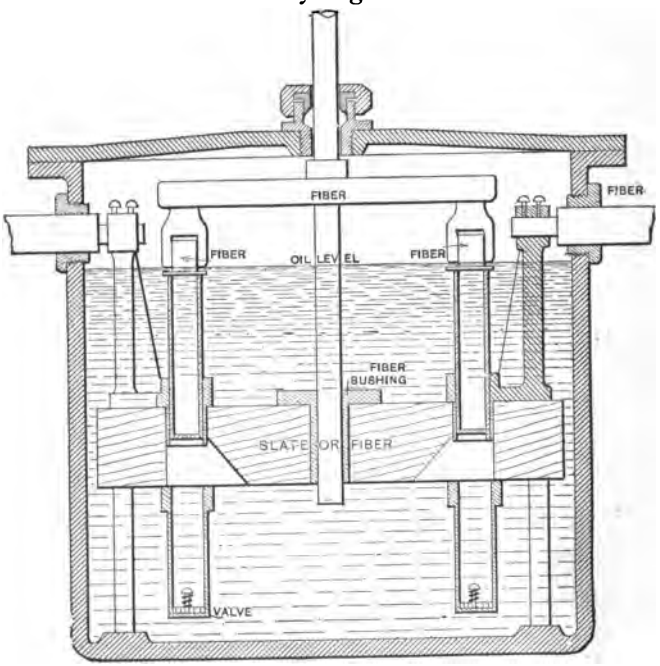

Figure 130. Oil break switch.

Some switches are arranged so that the contacts are separated under oil. This construction is illustrated in the vertical elevation Fig. 130. The box which holds the oil, and within which the switch is placed, is made of iron. and varies in dimensions according to the capacity

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of the switch. For a switch of about 25 amperes, and an e.m.f. of 2,500 volts, the size is about 6 x 4 x 7 inches. The current enters the box just above the level of the oil and passes down through side posts to bushings held on the upper side of a slate slab. The switch carries plugs which slide through these bushings and into tubes located directly under them and secured to the under side of the slab. The number of the plugs varies with the e.m.f. of the current, being generally sufficient to make voltage at each break not over 800. The tubes and the plugs are properly connected with each other so as to form a continuous circuit when the switch is in the closed position. The switch is moved by a hand lever controling central rod.

There is also another plan in use for reducing the size of the spark. In this design the switch contacts separate within a narrow passage, and on account of the restricted size of it the arc formed cannot be of very large dimensions. The switch is operated by pulling out the handle and the frame that holds the switch contacts is guided by the posts as is clearly shown in the figures.

A very similar switch is shown in switchboards, Figs. 75 and 76, shown in the latter figure in the form of a cross above the rheostats.

Switches intended for carrying very strong currents are in some instances arranged so as to be operated by compressed air. A switch of this type is used at Niagara Falls. The operation is the same, except that a compressed air cylinder controls the movement. A very high resistance is interposed between the first and second set of contacts, so that when the first break, the current is immediately cut down by the increased resistance in the

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circuit, and when the final break occurs, the strength of the current is much reduced. The switch shown in the illustration is of the four-pole type, and at each pole there is one knife break and eight tubular breaks. The switch is used in connection with two phase currents, and there are two poles for each circuit, hence at the primary break the circuit is interrupted at two points, and at the final break it is interrupted at sixteen points, so that the e.m.f. per break is one-sixteenth of the total line e.m.f.

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Circuit Breakers.

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A circuit breaker is a switch so constructed that it will open the circuit automatically when the current reaches the strength at which the device is set to operate. A circuit breaker in its most elementary form is shown in Fig. 131. The coil of the magnet M is connected in series in the circuit that is to be protected. The core C of this magnet exerts an attractive force upon the end A of the lever L, and when the current strength rises to a certain point the attraction becomes sufficient to overcome the weight of the end S. When this occurs, A is drawn against the end of C and S separates from N, thus opening the circuit. If a sliding weight is placed upon the end S of the lever, of if in addition to the weight of the tension of a spring, pulling downward, has to be overcome, it is evident that by moving the weight further from the fulcrum B, or by increasing the tension of the spring, the resisting force can be increased, and thus the device can be adjusted so that O will be drawn against C with such strength of current as may be desired. To make the apparatus a circuit breaker it is necessary to provide the catch t, for without this it would be simply a current interrupter. As can be readily understood, if there were no catch the lever would drop away from C soon after being attracted, for the separation of S from N would interrupt the current and therefore the strength

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of the magnet would die out. This type of circuit breaker would answer every purpose for currents of very low voltage and amperage, but would not operate success-

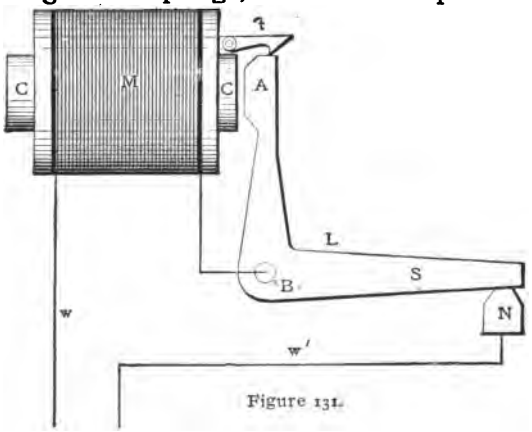

Figure 131.

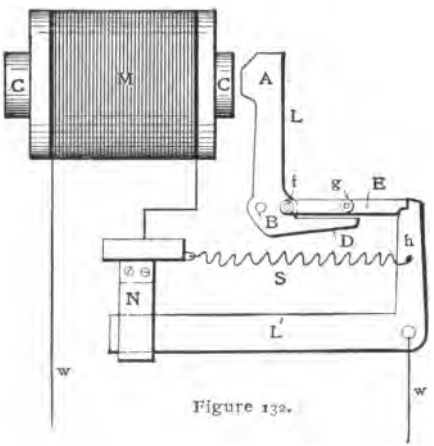

Figure 132.

Two simple forms of circuit breakers.

fully with such currents as are used commercially for lighting and power purposes. It would fail, first, because

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the contact between S and N is not perfect enough to prevent overheating, and secondly, because the width of the separation would not be sufficient to prevent the current from continuing to flow across the gap, thus forming an arc that would burn out the contacts in short order.

By elaborating the design of Fig. 131, as shown in Fig. 132, we can obtain a device that will operate successfully on a light power circuit.

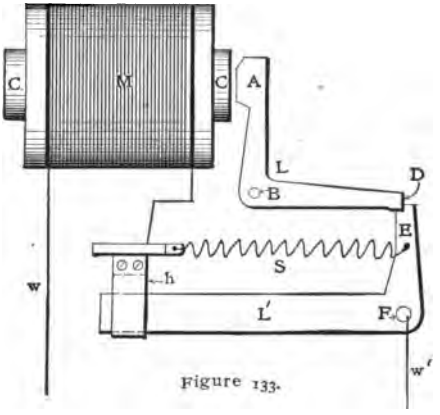

Figure 133.

Another variety of circuit breaker.

Fig. 133 shows one way of reducing the friction, which consists in using a brace jointed at the center, to hold the switch lever in place, this brace being forced out of line by the movement of the lever.

Fig. 134 shows another arrangement by means of which the friction may be reduced. In this construction a solenoid magnet is used, and the main switch is held in position by means of the catch at the end of the small lever 1. The lower portion of plunger i is made of iron, and the upper part, which is drawn with lighter shading, is made of brass, and on that account is not attracted by

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the magnetic force of the solenoid. When the solenoid becomes sufficiently strong to raise the plunger i, the pull

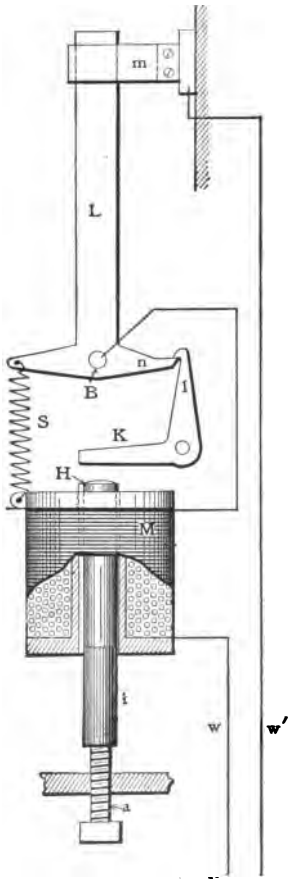

Figure 134.
One more way for breaking circuit.

increases as the rod moves up, thus rapidly accelerating the motion, the result being that the end of H strikes K

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an actual blow, the jar of which is great enough to dislodge the catch at the upper end and thus release switch L. By varying the position of i, the force exerted upon it by the solenoid can be changed so that the device can be set so as to trip with currents of different strengths. This position of i is varied by means of the screw A.

The principles illustrated in Figs. 133 and 134 are those most commonly used in the construction of commercial circuit breakers for continuous current circuits. Fig. 135 is a line drawing of a circuit breaker acting upon these principles. The solenoid coil is at B and C is the plunger, while M is the adjusting screw, by means of which the device is adjusted to trip with any desired current. When C is lifted it strikes E and thus throws up the trigger H, allowing the catch F to release G. The plunger I, which is forced outward by the spiral spring, impinges against the switch at K and throws it open, thus breaking the circuit. The switch contacts are arranged with double breakers, one being made of copper and the other of carbon. The copper contacts separate first, and the circuit is finally broken between the carbon contacts.

The carbon break circuit breaker, as manufactured by the General Electric Company, Fig. 137, meets all demands for a small, reliable, automatic, protective device for direct and alternating current systems.

The operation of the circuit breaker is absolutely positive, and it can be adjusted to trip at any predetermined point between its wide limits of calibration. A fuse is inflexible in this respect; its time lag is appreciable and more or less dependent upon climatic conditions; it can never be absolutely relied upon to rupture at its rated capacity.

Through the use of a double or triple pole circuit

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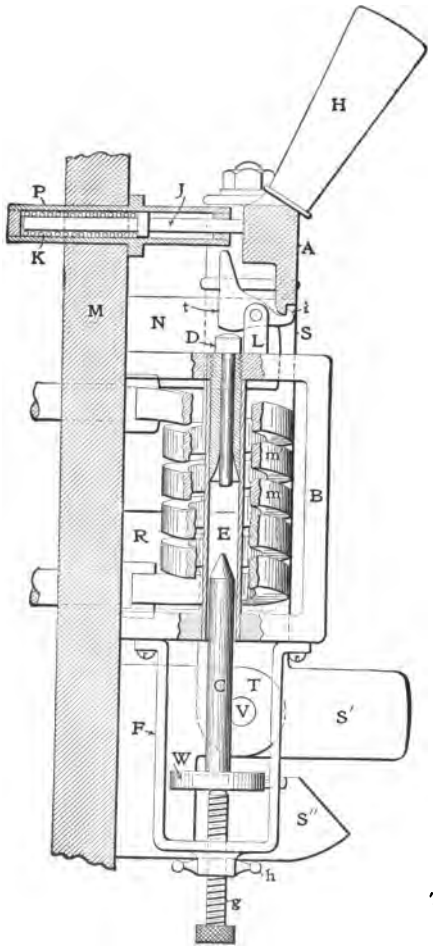

Figure 135.

Part Section Standard Switchboard Type Circuit Breaker.

A—Iron Jacket
B—Solenoidal Coil.
C—Movable Plunger.
D—Fixed Plug.
E—Striker Pin.
F—Catch of Striker Plate.
G—Catch of Switch Arm.
H—Striker Plate to throw Switch out.
I—Spring Piston.
J—Spring Tube, head removable.
K—Steel Striker Plate on Arm.
L—Buffer Springs.
M—Adjusting Screw.

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breaker with independently operated arms, the usual lever switch in series may be dispensed with, since such a circuit breaker performs the functions of both switch and single pole breaker. Either arm may be closed and is then free to trip, and will trip instantly in response to an overload or short circuit (should such exist) when the second arm is closed.

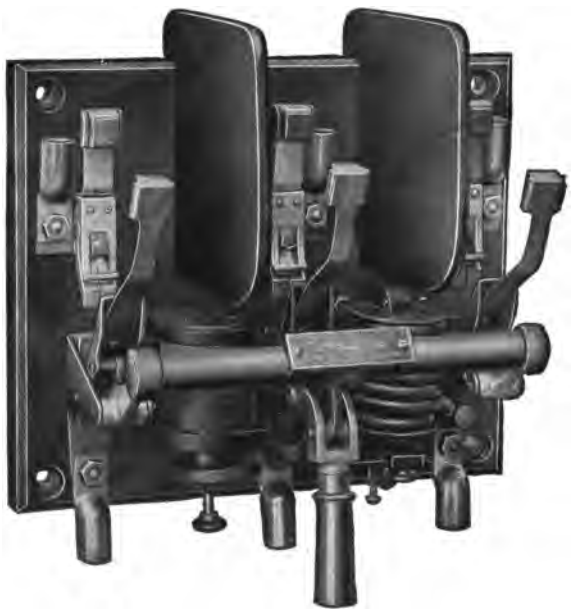

Figure 137. General Electric Co.'s breakers.

Circuit breakers of the type shown in Fig. 137 are suitable for every class of service requiring automatic protective devices, and are used extensively in steel mills, machine shops employing electrically driven tools, office buildings, etc. They are indispensable for general motor

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work, automobile charging sets, cranes, and electrically driven machinery in general.

The laminated brush is a feature of this circuit breaker. In closing the breaker a rubbing motion is imparted to the brushes which insures clear contacts.

The circuit is finally broken and the arc ruptured by

Figure 138. General Electric Co.'s circuit breaker.

means of carbon contacts of simple construction securely fastened to metal arms. The carbon blocks may be quickly and easily replaced if burned.

Extreme ease of operation is secured by the use of a toggle movement, and *the breaker will not jar out,* nor will it open unless purposely tripped by hand or actuated by the automatic tripping device in the event of an overload or short circuit.

The tripping point may be varied by adjusting the air

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gap between the electro-magnet (overload coil) and its armature. With the exception of those in the underload circuit breaker, no springs are used in the tripping device, the force on the armature being opposed to gravity. The trip is positive, the pull on the armature increasing as the air gap decreases, consequently when the armature begins to rise it will continue to do so with increased force until

Figure 139. General Electric Co.'s circuit breaker.

the breaker trips. With this construction any danger from "creeping loads" is obviated.

Two other types are shown in Figs. 138 and 139.

It will be noticed that in this circuit breaker each switch blade is held by an independent catch; on this account it can be used as a main switch at the same time that it acts as a circuit breaker.

Why this is the case will be understood from the following: A circuit breaker may act because the current

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is increased beyond the maximum strength on account of an abnormal load upon some motor, or because there is an excessive drain of any kind. It may also act, however, on account of the insulation in some part of the cir cuit giving out and thus establishing a short circuit. If the abnormal increase in current arises from the first-

Figure 140. General Electric Co.'s circuit breaker.

named causes, it is more than probable that by the time the attendant replaces the switch the demand will have reduced to the normal. If the circuit has acted on account of the current increasing through a short circuit, then it will rise to the same, when the breaker is reset, for the short circuit will still exist. Under such conditions it is injurious, more or less, to every device in the circuit to keep the circuit breaker closed for any length

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of time. If each side of the breaker operates independently of the other, there is no danger of closing the circuit when it is grounded—that is, if the device is handled properly.

In setting the breaker the proper procedure is to close one switch at a time. Closing the first one does not complete the circuit. As soon as the second switch is closed, if the circuit is short circuited, the current will rise beyond the maximum, and the first switch being free to act, will at once fly open again. If through stupidity the attendant tries to replace the first switch after having secured the second one, then the latter will fly open, and by that time he will come to the conclusion that there is something wrong. If both sides of the circuit breaker are tied together, it is possible to do considerable damage by holding the switch blade in position when the circuit is grounded.

To avoid such contingencies, a main switch is used, with such breakers, and in the proper handling of the devices the circuit breaker is closed first. Then when the switch is closed, if the current rises above the normal, the circuit breaker will fly open. The independent-action circuit breaker can take the place of the main switch, because when the second handle is raised into position the first one is free to swing back if the current rises to a dangerous strength.

Another way in which the disastrous effects of the arc can be reduced is by using a magnet to blow out the spark. A circuit breaker of the magnetic blow out type is illustrated in Fig. 140, showing the position of the operative parts when closed.

Fig. 141 shows how this circuit breaker is connected.

In the chapter on switches we showed designs in-

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tended for high e. m. f. currents in which the switch contacts are immersed in oil, and we also showed designs for large capacity switches in which the movement is effected by means of compressed air. Switches are also made so

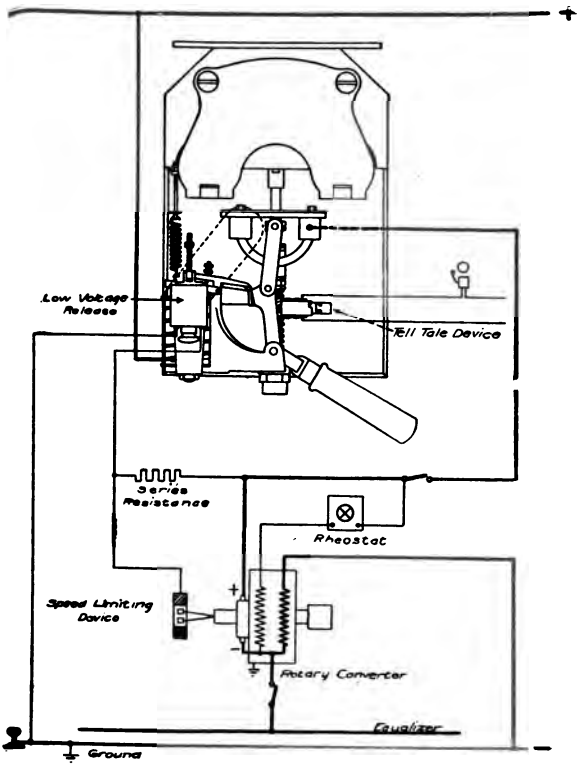

Figure 141. How to connect.

as to be immersed in oil, and at the same time so as to be actuated by compressed air. This construction, however, is only used for high e. m. f. and strong currents. Switches of this type are not placed on switchboards as

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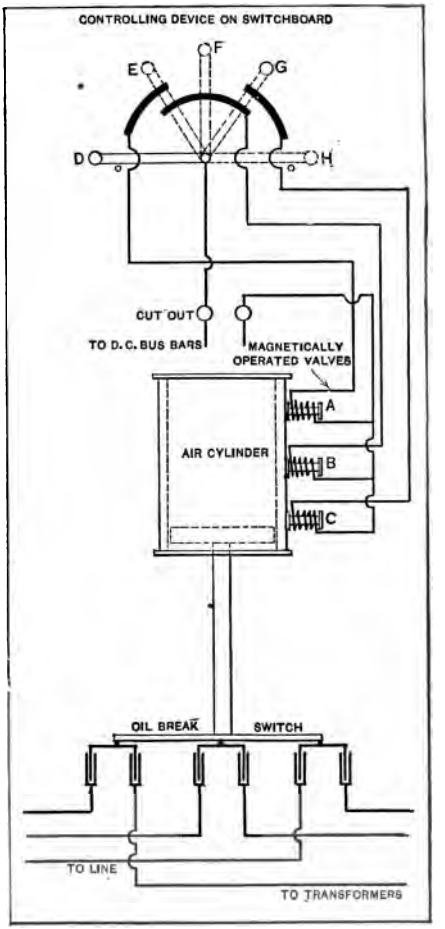

Figure 142
How some oil switches operate with compressed air.

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they are too bulky for such location but are mounted on independent stands.

These oil switches are provided with three magnets, one to operate a valve that admits air to the cylinder, at the upper end, and thus force the piston down; one to operate the valve which admits air to the lower end of the cylinder and thus force the piston upward. The third magnet acts upon a latch which holds either one of the two valves in the open position, except when the third magnet is energized. From the diagram Fig. 142, the way in which the circuit of these three magnets is arranged can be understood. When the controlling switch on the switchboards is in the position F, the current passes through magnet B which actuates the catch. When the switch is moved to position E the current passes through magnets B and A and air is admitted to the upper end of the cylinder. When the switch is in position G, magnets B and C are connected, and the valve at the lower end of the cylinder is operated. It can be seen that to make this switch automatic, or in other words, a circuit breaker, all that is required is to provide a magnet that will move the controlling switch at the upper end of the diagram.

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Lightning Arresters.

▼ ▼ ▼

A lightning arrester is a device used to protect the apparatus connected in an electric circuit from the destructive effects of lightning. For circuit in which the current is very small, as for example, telegraph and telephone lines, the lightning arrester is a simple device consisting of a pair of sheet brass plates having saw teeth on the edge; these being set so as to leave a space of about one-sixteenth of an inch between the ends of the teeth. One of the plates is connected with the circuit, and the other one with the ground. Fig. 143 shows the way in which such an arrester is arranged and connected. When it is desired to make the protection more complete, two sets of plates are provided and connected as shown. The first diagram forms a single pole arrester, and the second is a double pole arrester.

The e. m. f. of the current that normally flows through the circuit is not sufficient to strike across the space separating the teeth of the lightning arrester, but when lightning strikes the line wires the e. m. f. is at once raised to an enormous magnitude, and for such an e. m. f. the short air space between the plates is an utterly insignificant resistance. Not only will the lightning discharge pass through the arrester, and to the ground, but none of it will go through the coils of wire on the magnets of the telephone or telegraph instruments. Now inasmuch

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as the resistance of these coils is practically nothing in comparison with that of the air gap between the plates of the arrester, it may be asked, Why will lightning pass through the air gap and not through the wire coils?

This is not difficult to show. Suppose that the e. m.

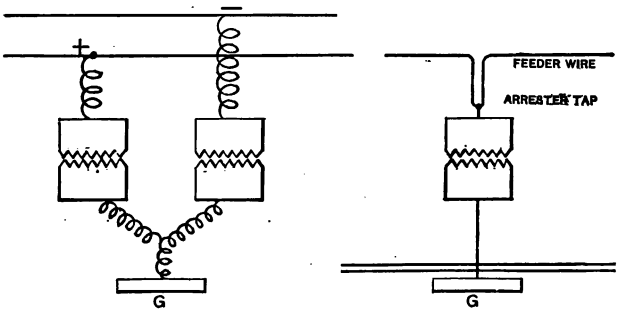

Figure 143. Lightning arresters.

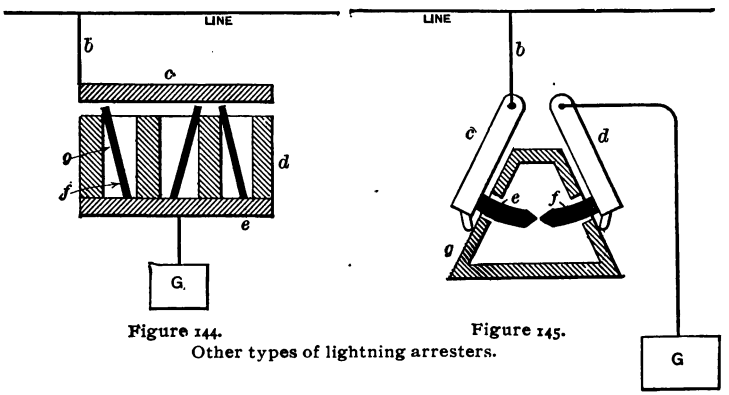

Figure 144. Figure 145.

Other types of lightning arresters.

f. of the lightning discharged is one million volts, then the instant it strikes the circuit, the e. m. f. is increased to one million volts. This instantaneous increase in e. m. f. produces an enormous instantaneous increase in the

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strength of the current, and consequently the reactance e. m. f. of even the smallest coils in the circuit becomes very great, so great as to far exceed the resistance of the air gap in the lightning arrester, hence the current passes

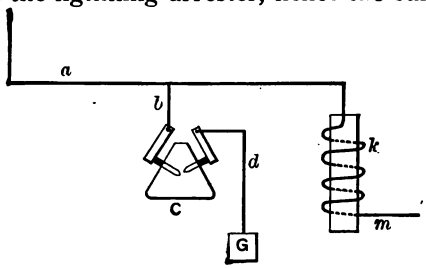

Figure 146.

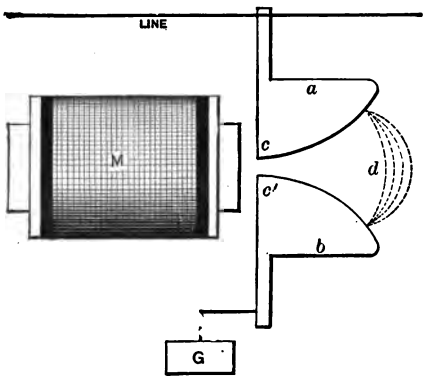

Figure 147.
Two magnetic blow outs.

to the ground through the latter path because it encounters less resistance. Lightning may strike a circuit that runs in the open air at any point, and from here the current will run both ways until it finds an escape to the ground. It follows, therefore, that if we desire to properly protect every device in the circuit, we must place

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arresters on both sides of every one if the connecting lines of both sides are so exposed that they can be struck.

Lightning discharges are prevented from passing through the wire coils wound upon the apparatus in the circuit, owing to enormous reactance of these, but they take the path through the arrester as an alternative simply because this offers less resistance than any other path. If there is a weak point in the insulation of any coil upon which the e. m. f. of the lightning is impressed, and this weak point is not very far from the entering point, then the discharge will break through the insulation at this point and pass to ground, or at least a portion of it will. From this it follows that to make an arrester as effective as possible, the resistance at the air gap must be as low as it can be without being liable to be bridged by the working current flowing in the circuit.

The simple type of lightning arrester illustrated in Fig. 143 cannot be used for circuits in which the currents have any considerable strength, that is, in circuit such as used for operation lights and motors. If such an arrester were placed in a light circuit, the result would be that the first time a lightning discharge passed to the ground, it would form a permanent ground connection, because the generator current would follow the lightning discharge and by producing an arc across the air gap would greatly reduce the resistance, making it so low that it could be readily overcome by the generator e. m. f.

For lightning and power circuits, it is necessary to so construct the lightning arresters, that the generator current cannot follow up the lightning discharge. This result is accomplished in several ways, one of which is illustrated in Fig. 144. In this diagram, b is the wire connecting the upper plate c of the lightning arrester

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with the circuit. The lower plate is located at e. A casing d, made of porcelain and provided with a number of holes, is placed between c and e. In the holes in d pieces of fuse wire are placed, these being of such length that they will not touch c, but come close to it, say, within a sixteenth of an inch. If, after a lightning discharge passes, the generator current persists in following, then the fuse wire through which it passes will be melted and thus the air will widen out and finally become so long that the current will break. After the device has acted a number of times, so many of the fuse wires will be destroyed that it will have to be recharged.

Figure 148. Westinghouse arrester.

Fig 145 shows a design in which the lightning discharge passes through carbons e and f placed within the chamber, but free to swing around the upper pivots. This arrester acts upon the principle that the heat generated by the arc formed between the carbon points in case the generator current follows up the lightning discharge, ex-

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pands the air within the chamber and thus forces the carbons out and in that way make the air gap so long that the e. m. f. of the generator cannot maintain the arc.

Fig. 146 shows a way in which lightning arresters

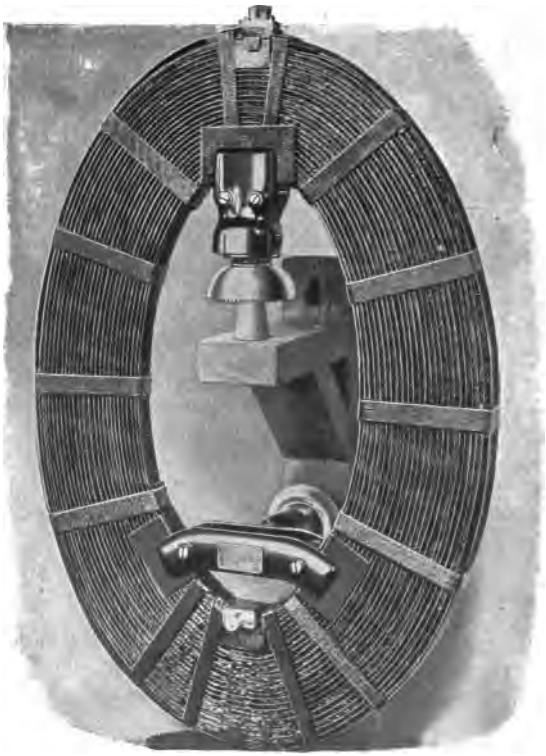

Figure 149. Westinghouse choke coil.

are combined with a reactive, or choking coil, to render them more effective. The reactance of the coil k acts to prevent the lightning from passing through and thus helps the discharge to break across the air gap in the

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arrester and also takes the strain off the apparatus beyond it in the circuit.

Fig 147 shows what is commonly called a magnetic blow-out lightning arrester. The magnet M, which is wound with rather large wire, is connected with the main line. When a lightning discharge passes to ground it

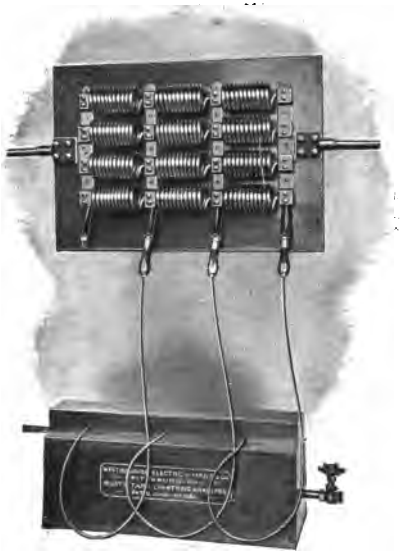

Figure 150. Lightning arresters for direct-current circuits. Tank lightning arrester for railway service, Type T.

bridges the points e e. If the generator current follows the discharge the line of force of the magnet force the current out of the position d, and when the arc is forced so far out as to make the length greater than the e. m. f. of the circuit can surmount, the current breaks.

Fig. 148 shows a form of lightning arrester that is used extensively in connection with alternating currents.

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The construction is clearly shown. It consists of a number of short cylinders made of non-arcing metal which are held close to each other in a porcelain casing. The lightning discharge strikes across from cylinder to cylinder until it reaches the ground.

One of the choke coils of an arrester, used in connection with alternating current circuits of very high e. m. f., is shown in Fig. 149, by connecting a large number in series, and combining these with a corresponding number of reactive coils. These arresters and coils are assembled in a frame with the arresters arranged at the top of the frame, and the coils piled side by side under them.

Fig. 150 shows a type of arrester for direct current circuits, especially electric railways.

A number of theories have been advanced to explain the action of so-called non-arcing metals. We know from experience that with some metals the length of arc that can be sustained with an e. m. f. is greater than with other, and a question naturally arises as to what causes this difference. If we investigate the action from the instant when the arc begins to form we will be able to discover what occurs, and thus be able to form some idea of the cause of the difference in action with different metals.

Suppose we take two rods of metal pressing against each other end to end. If we separate them the current will jump across the intervening air space. At the instant the arc is formed the resistance between the points is very high, being due to the length of the column of air between the points. The current passing over this resistance generates a large amount of heat, and this vaporizes the metal, thus filling the space between the ends of the

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rods with metallic vapor, which has a much lower resistance than the air. If the vapor is of high resistance, the amount of heat developed will be greater than if it is of low resistance and as a consequence more metal will be vaporized. If the resistance of the vapor is very low the amount of heat developed will be correspondingly low, and therefore the amount of metal vaporized will be comparatively small.

With a metal which gives a high resistance vapor, the heating is prevented from becoming very great from the very fact that the high resistance cuts down the strength of the current, and with the low resistant vapor the heat is prevented from becoming very small from the fact that he low resistance causes the current to increase in strength. Thus we see that while the high resistance vapor acts to confine a large amount of heat within a small space, it also acts to keep down the total amount of heat developed by reason of not permitting the current to rise to a considerable strength. On the other hand, the low resistance vapor enables a large current to flow, and thus a large amount of heat to be developed, but this is distributed over a much larger volume of vapor.

From these facts it follows that if the vapor is of high resistance, the arc will be of small crossection, which will help to increase its resistance, while if the vapor is of low resistance the arc will be of large cross-section which will help to reduce its resistance. The conclusion we are naturally led to, therefore, is that the higher the resistance of the vapor of a metal, the smaller the arc sustained between the ends of rod made of that metal. If two metals whose vapor has the same specific resistance are of different fusibility, then the two which melt at the highest temperature will be vaporized, the

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least with a given amount of heat, therefore, the resistance of the arc produced by it will be the greatest. We therefore see that a non-arcing metal is one which does not vaporize readily, and whose vapor has a very high resistance. Experimentally it is found that zinc and antimony are about the best non-arcing metals we have. Now both of these fuse at low temperature, so that the only conclusion we can come to is that the resistance of their vapor is sufficiently high to overbalance the low fusibility.

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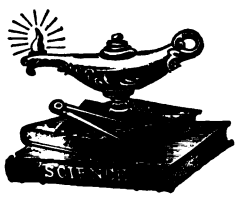

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